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Full Length Research Paper

Status of soil properties of scattered *Faidherbia albida* (*Del*) in agricultural landscapes in Central Highland of Ethiopia

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Scattered trees in general and scattered *Faidherbia albida* in particular are preserved in agricultural landscapes in Ethiopia. A study on this tree species was conducted at Meskan District of Gurage Zone, Ethiopia with the objectives of assessing the status of soil properties under it and its population distribution in agricultural landscapes. Twenty four soil samples from the surface layer (0-10 cm) were taken from under six isolated mature *F. albida* trees at 3 concentric transects (1, 3 and 5 m) from the tree trunk and compared with soils taken from the adjacent open areas, 12 m far from the trees. In addition, 24 undisturbed soil samples were also collected from same points using core samplers for bulk density and moisture content determinations. The collected soil samples were analyzed following standard laboratory procedures. Assessment of the population distribution of the species was carried out at three different altitudinal zones, that is,1800-2000 m above sea level (asl), 2000-2200 m asl and 2200-2400 m asl and from four land use types (homestead, farmlands, woodlots and grazing land). A complete count and Y frame transect sampling methods were used to estimate number of stem per ha. The results revealed that organic matter (OM%), organic carbon (OC%) and total nitrogen (TN%) significantly differ between radial distances. The three parameters, were higher at 1 m distance compared with the values at 5 and 12 m distances. Though the difference is statistically not significant, available P and moisture content (MC) showed a decreasing trend, and bulk density (BD) and carbon nitrogen ratio (C/N) showed an increasing trend with increasing distance from the trees trunk. Population status of *F. albida* in the farms is dominated by higher diameter classes, with only 2% share of stems in the younger DBH-class of less than 5 cm. This may not indicate a threat to the species as it appear as the community do not cut and harvest the whole tree but only lop which eventually may prolong the life span of the trees. Thus, this finding suggests that scattered *F. albida* trees are important agro-forestry resource to sustain soil fertility and subsequently crop yields. They are also important sources of multiple products such as fodder and shade for livestock during dry period, fuel and fencing material for households.

Key words: *Faidherbia albida*, soil property, population status, sustainability, Ethiopia.

INTRODUCTION

General background

In Ethiopia, a downward spiral of soil fertility has contributed to a corresponding decline in crop yields, an increase in food insecurity continued dependence on food aid. One option for helping to move towards food security, which still remains a major challenge in the country, and to concurrently minimize environmental

degradation, is to promote agro-forestry that specifically involves indigenous trees species (Lalisa, 2010; Kindya, 2004; Poschen, 1986). A number of potential tree species for agro-forestry use in the drylands of Eastern Africa are available for the purpose of both resource conservation and poverty alleviation (Kindya, 2004).

Faidherbia albida (formerly called *Acacia albida*) is one of the dominant tree species deliberately retained on farmlands across most African dryland ecosystem (Phombeya et al., 2005; ICRAF, 2000; Poschen, 1986). *F. albida* is a multipurpose tree that is used to provide fodder and fuel wood and also to prevent soil degradation and promote biodiversity (Mokgolodi et al., 2011; Phombeya et al., 2005; Poschen, 1986; Adamu, 2012). The existence of *F. albida* in agricultural landscape in Ethiopia signifies the success of this traditional land-use practice in serving multiple purposes including improving crop yield and soil fertility. Modern scientists have also developed keen interest in understanding how *F. albida* promotes more sustainable agricultural production systems (Mokgolodi et al., 2011).

Several authors have reported the effects of the tree species on soil fertility and associated crop yields in Ethiopia (Manjur et al., 2014; Kiros et al., 2009; Hadgu et al., 2009; Kamara and Haque, 1992; Poschen, 1986) in Ethiopia. For example, Hadgu et al., (2009) and Kamara and Haque, (1992) found higher soil moisture content, organic carbon, total nitrogen, available P in the zone under *F. albida* tree canopy than zones far away from the tree canopy. Another study by Poschen (1986) reported higher crop yield in Zone under *F. albida* tree canopy than Zone far away from the tree canopy. Similar study by Manjur et al. (2014) indicated that there are significantly higher soil nutrients (C, N, P K) and yield of maize under *F. albida* and *Croton macrostachyus* trees than far from canopy in Southern Ethiopia.

A study by Sanda and Atiku (2013) showed that a significant differences in OC, N, P and K between distance from tree trunk in Nigeria. Saka et al. (1994) and Umar (2012) also found significant effects of *F. albida* on soil and crop yields in Malawi and Zambia, respectively. In the current study area, large tracts of agricultural landscape is covered by scattered trees predominantly, *F. albida.* However there are no studies that considered the effects of these trees on soil properties, and the status of the population of the tree species in study area. In recent years, farmers seem to have hampered the regeneration of *F. albida* because of the widespread poor agricultural practice and lack of awareness. Hence, research based information is crucial in order to convince land users and policy makers for corrective measures for promoting the integration of this multipurpose tree in the farming system. Such information can also be helpful in designing appropriate land use measures for improving soil nutrients, crop yield and biodiversity in agricultural landscapes. Therefore, this research was designed with the objectives of assessing (1) the variability in soil properties (MC, BD, pH (H20), SOM, organic C, total N and available P between radial distances from tree trunk (2) the overall relationships of the selected soil physical and chemical properties and radial distance, and (3) status of the population distribution of the trees at three altitudinal zones and four land use patterns.

MATERIALS AND METHODS

Geographic location

This study was conducted at Meskan District located between 38∘15'10.7"- 38∘33'510.9" E and 8∘1' 598.8" - 8∘16' 3029.6" N in Gurage Zone of Southern Ethiopia. This District was selected based on the existence of abundant *F. albida* trees under in agricultural landscapes. The population status of *F. albida* was assessed in three localities: Goyban, Mekicho and Ile while soil status was assessed only at Ile (Figure 1).

Biophysical environment of the study area

According to climatic record near the study area, the mean annual rainfall in the District (Figure 2) is 1058 mm and the mean daily maximum and minimum temperatures are 27.7 °C and 6.5°C, respectively (Figure 2) National Meteorology Services Agency, 2005. The main growing season begins towards the end of June and continues up to the end of October. The District has an altitude ranging from 1800-3500 m above sea level (asl). The dominant soil types of the District included eutric Cambisols, chromic Luvisols, chromic Vertisols, eutric Fluvisols , Leptosols and pellic Vertisols. The soil in the specific study site (Ile) is pellic Vertisols. The major land use and land cover in the area include farmlands, grasslands, plantation forest of mainly eucalyptus species, natural forest including area exclosure and degraded hillside. Growing indigenous on- farm trees such as *Faidherbia albida*, *Acaica abyssinica*, *Acacia seyal*, *Cordia africana* and *Croton macrostachyus* together with annual crop is a common practice in the area. The dominant annual crops associated with the on-farm trees includes teff (*Eragrostis tef* (Zucc.)), wheat (*Triticum sativum* L), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L) and green paper (*Capsicum frutescens* L.).

Experimental design, soil sampling and analysis

For the soil study, six isolated mature trees of *F. albida* were selected at six adjacent farmlands under similar soil types, climate and landscape. Twenty four soil samples were taken from the surface layer of 0–10 cm at three concentric transects of (1, 3 and 5 m) and compared with soils taken from adjacent open areas located at 12 m from the trees trunk. Approximately, 1 kg of soil sample was collected from each sample site and analyzed at Holetta soil laboratory. The samples were air-dried at room temperature, crushed, homogenized and passed through a 2mm sieve before analysis for pH, C and available P. They were also further sieved throug 0.5 mm size for analysis for TN. For bulk density and
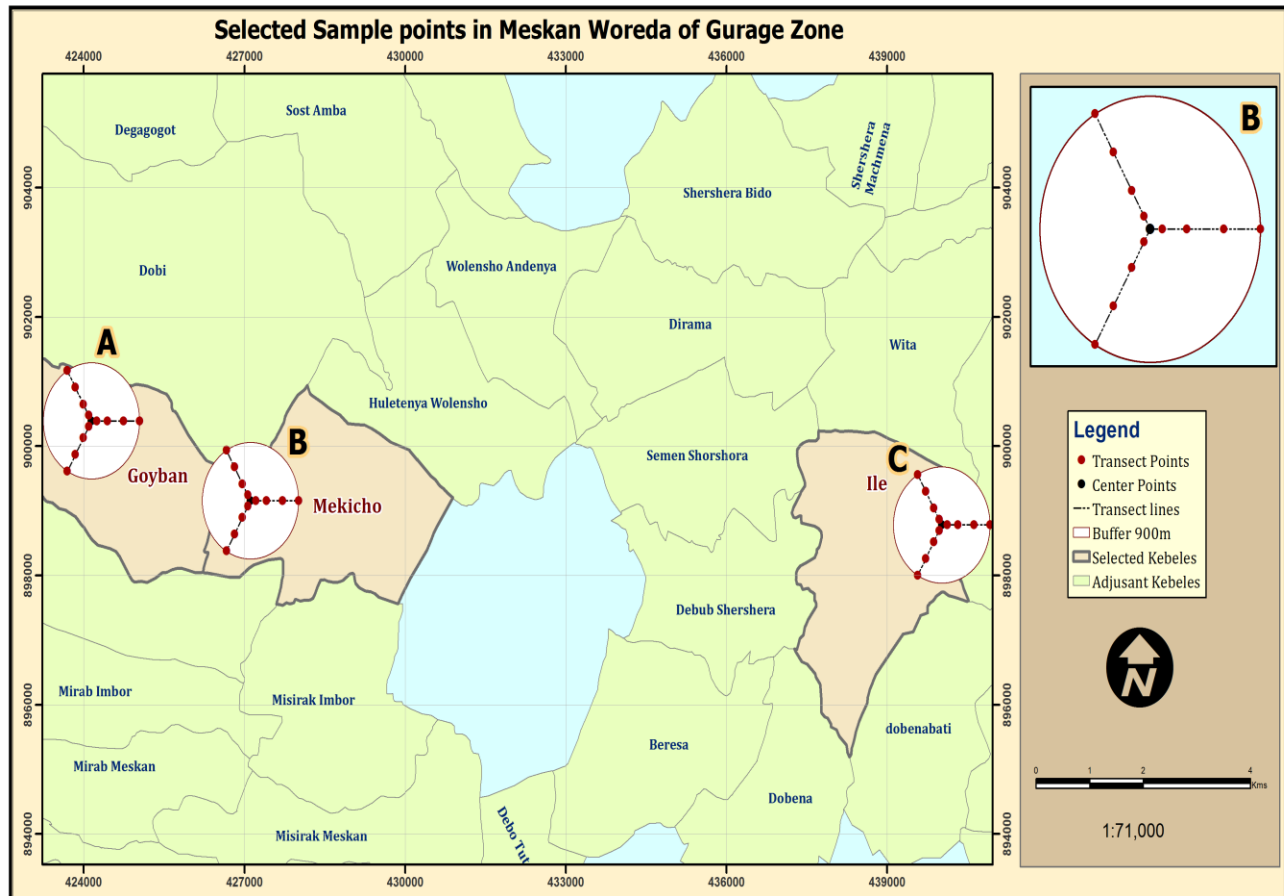
Figure 1. Farm sampling method. (A, B & C) GPS points were randomly located in three Peasant associations of (Goyban, Mekicho and Ile) in Meskan district (B) from each GPS point three axes departing 120° from each other were demarcated, and four GPS points were located along each axis, at 100, 300, 600 and 900 m from the center; (B') detail of a Y-sampling frame indicating the 13 GPS points and the GIS polygons representing the adjacent farms to each of the points, which were selected for field survey.

moisture content determination undisturbed soil samples were also collected with a manual core sampler of 5 cm height and * 3 cm in diameter at soil depth (0-10cm).

Available Phosphorus was determined by Olsen's method of bicarbonate extraction (Olsen and Summer, 1982), total nitrogen was analyzed by Kjeldahl procedure (Jackson, 1958), and organic carbon was determined by Walkley-Black dichromate method (Walkley and Black, 1934), pH was measured using (1:2.5 soils to water ratio) using digital pH meter. Bulk density was determined using core method after oven drying wet undisturbed soil samples at temperature of 105°C for 24 h. Soil-water content was determined by standard procedures described for the gravimeter method after oven drying to a constant weight at 105°C (Anderson and Ingram, 1993) for 30 h. Bulk density was calculated by dividing the weight of oven-dried soil with the volume of the core. OM was estimated by multiplying OC by 1.724. All the chemical and physical analysis were carried out in a soil-testing laboratory of Holetta Soil Laboratory, Addis Ababa Ethiopia.

Assessment of population status of *F. albida*

Inventory of *F. albida* was carried out in three Peasant Associations

namely Goyban, which is a high altitude area (2200-2400 m asl); Mekicho a mid altitude area (2000-2200 m asl), and Ile a low altitude area (1800-2000 m asl). Three GPS points were selected randomly one in each locality, then a Y-frame transect sampling scheme applied for selecting 39 farms for detailed study. That means 13 farms were selected from each locality along the three transects line approximately at 100m, 300m, 600m and 900m from central farm (Figure 1). The selected farms were further categorized into four land uses (homestead, farmlands, grazinglands and woodlots). The size of each farm/plot was determined through interview of the owners and field survey. Total count method was used to estimate the number of stems per plot. In addition, Diamter at Breast Height (DBH), total height and canopy width and length were measured using caliper, clinometers and measuring tape, respectively. In addition, semi-structured interview, field observation and informal discussion was held to capture qualitative data.

Statistical analysis

The data of soil properties in response to radial distance were subjected to GLM test with one-way-ANOVA (SPSS Inc, 2006). Then, the means for treatments that showed significant differences
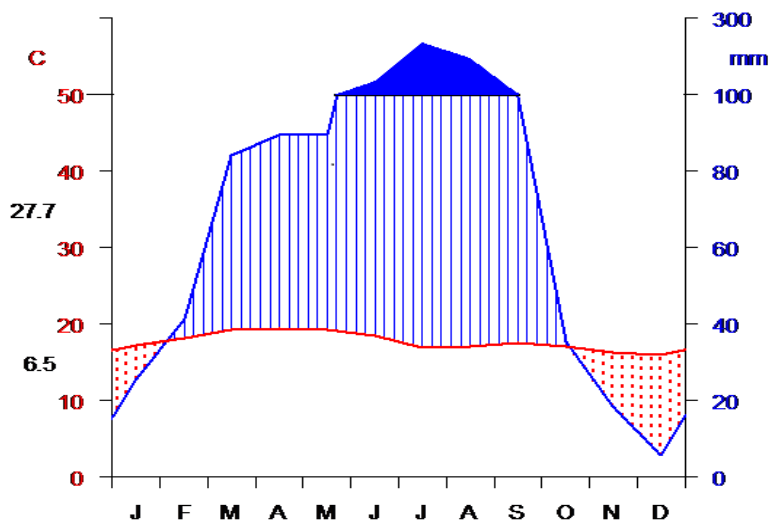
Figure 2. Climatic condition of Meskan area based on a long-term data (1990–2012).

Table 1. Mean of soil MC (%) and BD (g cm^{-3}) of soil at 1, 3, 5 and 12 m.

Property	Distance from tree trunk (m)				ANOVA
	1	**3**	**5**	**12**	
MC (%)	29.53±1.01[a]	28.75±1.13[a]	28.35±1.45[a]	28.32±1.49[a]	ns
BD (g/cm^3)	1.12±0.04[b]	1.13±0.03[b]	1.14±0.06[b]	1.15±0.02[b]	ns

Values followed by the same letters in a row are not significantly deferent at p<.05; or 0.001*.

RESULTS and Discussion

Soil physical properties

Results of soil moisture content and bulk density are presented on Table 1. Both sSoil moisture content and bulk density did not show any significant difference (P < 0.05) difference between the radial distances (Table 1). However, relatively higher moisture content of (29.53±1.01%) was recorded at 1m distance, while similar lower moisture content of 28.75±1.13%, 28.35±1.45%, 28.32±1.49% were recorded at 3m, 5m and 12m distnaces, respectively (Table1). This result

by F-test were separated by Tukey's honestly significant difference test (Tukey-HSD test) and significance were declared at 0.01 and 0.05 significant levels, which is the most widely used multiple comparison procedure (Zar, 1996). Correlation test was conducted to assess the relationships between the different soil properties and radial distances. The soil properties analyzed and compared were bulk density(gcm^{-3}), moisture content(%), pH(H$_2$O), OC(%), SOM(%), total N(%), available P(ppm) and C/N. Similar GLM test with one-way-ANOVA was used to evaluate the effect of land use and altitude on stem number of *F. albida*. In addition, simple descriptive statistics was used to describe distribution and characteristics of trees and qualitative data.

goes well with the finding of Manjur et al., [2014] who found non-significant difference in moisture content between radial distances from tree trunk under *F. albida* and *C. macrostachyus* in Southern Ethiopia. The result also conforms with the studies by Hadgu et al., (2009) and Kamara and Haque (1992) who found no significant difference in moisture content between radial distance in Ethiopia. On the other hand, the present result disagrees with the finding of Rhoades (1995) who found higher moisture content under the canopies of *F. albida* trees than outside the canopy. Though not significantly different, lower BD of 1.12±0.04g/cm3 was observed at 1m, and slightly higher BD of 1.13±0.03 g/cm3, 1.14±0.06 g/cm3 and 1.15±0.02 g/cm3 were measured at 3m, 5m and 12m radial distances, respectively (Table 1). This observation contradicts with that of Manjur et al., (2014) found a significant difference in bulk density between radial distances from *F. albida* and *C. macrostachyus* trees in Southern Ethiopia. Bit the result is consistent with findings of Abebe (2006) who reported lower non-significant bulk densities under *F. albida*, *C. macrostachyus* and *C. africana* trees in Eastern Ethiopia. It also matches with the finding of Belsky et al (1989), who reported lower bulk density under trees than outside the canopy in Kenya.

Table 2. Mean ± SEM of soil OC (%), OM (%), TN (%) available P (ppm), pH (H$_2$O) and C/N at 1, 3, 5 and 12 m.

Property	Radial distance from tree trunk (m)				ANOVA
	1	3	5	12	
OC (%)	2.74±0.08[a]	2.62±0.07[ab]	2.44±0.09[b]	2.35±0.04[b]	*
OM	4.7±0.14[a]	4.5±0.18[ab]	4.21±0.15[b]	4.04±0.08[b]	**
TN (%)	0.21±0.02[a]	0.19±0.01[ab]	0.18±0.00[b]	0.17±0.00[b]	**
P (ppm)	17.10±2.02[a]	16.10±0.66[a]	14.81±0.88[a]	15.16±0.11[a]	ns
C/N	13.49±0.83[b]	13.72±0.4[b]	13.95±0.40[b]	14.23±0.24[b]	ns
pH	6.18±0.06[a]	6.15±0.09[a]	6.11±0.07[a]	6.12±0.07[a]	ns

Values followed by the same letters in a row are not significantly deferent at p<.05; or 0.001*.

Soil chemical properties

Among the selected soil chemical properties, OC, SOM and TN showed significant differences with radial distances (Table 2). Soil pH did not show significant difference. A roughly similar soil pH of 6.18±0.06; 6.15±0.09; 6.11±0.07 and 6.12±0.07 were observed at 1, 3, 5 and 12 m distances from the trees trunk, respectively (Table 2). This result goes well with the finding of Manjur et al., (2014), who reported similar soil pH among radial distances from trunks of *F. albida* and *C. macrostachyus* in Southern Ethiopia. Another study by Kamara and Haque (1992), also found similar soil pH under and outside the canopy of *F. albida* in Ethiopia. Jiregna et al.,(2005) also reported a similar patter of soil pH under and outside canopy of *C. africana* and *C. macrostachyus* in Eastern Ethiopia. OM was significantly different between radial distances (P < 0.01). Higher OM of 4.7± 0.14% was measured at 1m whereas lowest OM of 4.04±0.08% was measured at 12m. Both OC and OM content showed a continuous decline with radial distances from the tree base. This may reflect the strong influence of trees on organic inputs. Likewise, organic carbon significantly varied at (P < 0.05) among radial distances. Higher OC of 2.74±0.08 % was found at 1m while lowest OC of 2.35±0.04% were found at 12m distance (Table 2). In general soil under tree canopy contained better soil chemical attributes than outside the tree canopy. These results agree with previous reports by Abebe, (2006) and Manjur et al., (2014) who found higher OC under the canopy *F. albida*, *C. africana* and *C. macrostachyus* than outside canopy in Ethiopia. It is obvious that OM has a positive influence on soil fertility, plant nutrition and biological activity in the soil (Brady and Weil, 2002).

Total nitrogen also showed a similar significant difference (P < 0.05) between radial distances. Higher TN (0.21± 0.02%) was measured at 1m distance and lowest TN (0.17±0.00%) was measured at 12m distance (Table 2). This results matches the findings of Hadgu et al., (2009) and Umar et al., (2012) who found higher N content under the canopies of the trees than far away from the influence of trees in Ethiopia and Zambia.

Another study by Kamara and Haque (1992) also found a higher N content under *F. albida* canopies than outside the canopies in Ethiopia. Similar other studies (e.g. Abebe, 2006; Manjur et al., 2014; Sanda and Atiku, 2013; Saka et al., 1994) reported a similar pattern of difference in total N between radial distances.

The observed higher SOM, OC and TN under canopy compared with open area could be explained due to leaf litter fall and decomposition of dead roots from the tree and nutrient cycling and nitrogen fixation by tree species. Shedding of its leaves during rainy period when there is limited livestock movement might be a contributing factor for higher soil fertility under canopy compared with outside the canopy. It is obvious that *F. albida* has the ability to fix atmospheric nitrogen and subsequently convert it to plant available nitrate form (Buresh and Tian, 2004). For instance, Kamara and Haque (1992) found higher content of N (3.85%) from fresh leaves of the trees in Ethiopia. On top of this, deep rooting system of *F. albida* enables the tree to take up nutrients from deeper soil horizons and that are subsequently returned to the top soil through litter fall. Some of the key informants estimated that the root of *F. albida* system extends up to 25m down ward for extraction of nutrients and moisture. In present study the contribution of external sources such as cattle dung is could be minimal as farmers regularly pollard the tree canopy for reducing shade that can pose problem on associated food crops.

On the other hand, available P did not show significant difference among radial distances (Table 2). However, relatively higher available P of 17.10±2.02 ppm was measured at 1m while relatively lowest values of available P (14.81±0.88 ppm), was measured at 5m (Table 2). This result goes well with findings of Abebe (2006) who found better available P under *F. albida*, *C. africana* and *C. macrostachyus* trees in Ethiopia. These results also confirm the findings of Kamara and Haque, (1992) who detected non-significant variability of available P among radial distance under *F. albida* in Eastern Harargie, Ethiopia.

The result, however, does not match with the findings by Manjur et al., (2014) who reported significant difference in available P among radial distances from tree

Table 3. Pearson's correlation matrix for OM (%), TN (%), Ava. P (ppm), pH, MC (%) and BD (g/cm^3).

Soil property	SOM (%)	TN (%)	pH	BD (gm/cm^3)	MC (%)	P (ppm)	RD (m)
SOM (%)	1						
TN (%)	0.696**	1					
pH	0.467*	0.253	1				
BD (gm/cm3)	-0.536**	-0.287	-0.503*	1			
MC (%)	0.582**	0.310	0.768**	-0.541**	1		
P (ppm)	0.225	0.485*	-0.358	0.006	-0.250	1	
RD (m)	-0.690**	-0.670**	-0.048	0.149	-0.088	-0.267	1
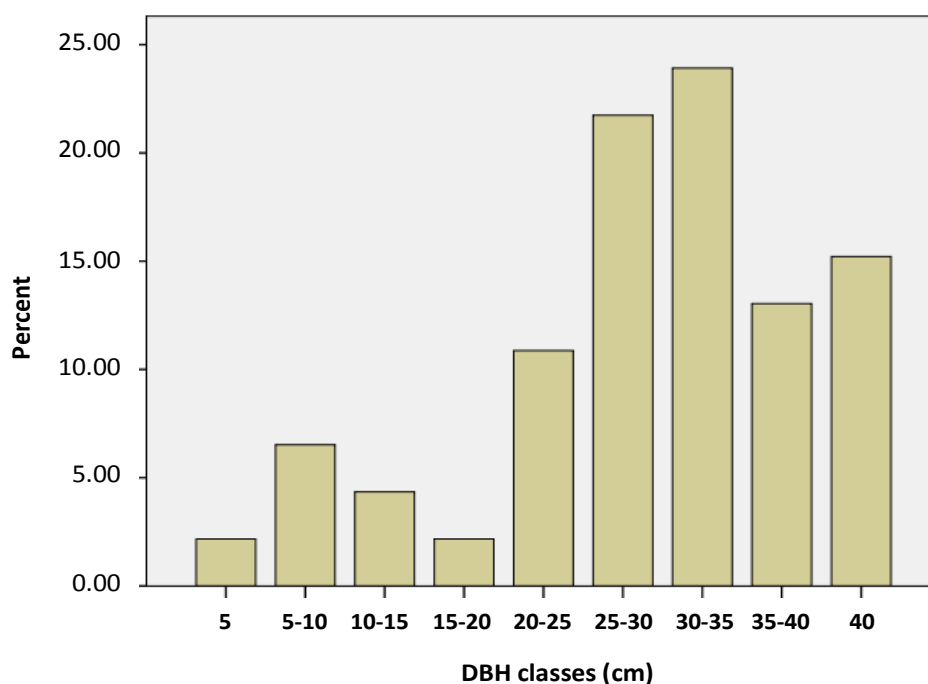
Figure 3. Distribution of *F. albida* in DBH-class (cm) in Meskan District, Ethiopia.

trunk under *F. albida* and *C. macrostachyus* trees in Southern Ethiopia.

Likewise, C/N ratio did not show significant difference among radial distances. Nonetheless, there is an increasing trend with increasing radial distance as shown in Table 2.

Correlation assessment between the different soil parameters (Table 3) revealed a positive correlation between SOM, N, pH and MC. Similarly, positive correlation was observed between TN and P. The relationship between SOM and BD was negative, which is expected. The higher the SOM, the lower the bulk density should be. Radial distances, and SOM and TN are also negatively correlated, which again is expected. This again confirms the positive effect of trees on SOM and TN. Similar inverse relationships between radial distances and SOM, N, P, K were reported from Ethiopia

by Kamara and Haque (1992) and Umar et al,.(2012) from Zambia.

Distribution and characteristic of *F. albida* trees in the study area

Tree stem distribution by DBH class indicated 74% of the stems to fall in the DBH class over 25 cm, while only a lower proportion of (2%) fall in a yunder (juvenile) DBH-class of less than 5cm (Figure 3). This shows the dominance of mature trees. This finding matches with the study of Kamara and Haque (1992) who reported higher proportion of mature trees compared with young trees in a similar farming system in Ethiopia. The present results also goes well with finding from other area by (Adamu, 2012) and Reed et al., (1992) who found higher

Table 4. Mean±SEM of number stems of *F. albida* in relation to land use (Homestead, Farmlands, Grazing land and *Eucalyptus camaldulensis* woodlots.

Parameter	Altitudinal zone	HG	FL	GL	WL	ANOVA
Number of stems per ha	1800-2000	9.26±3.04	10.04±2.44	6.25±6.25	4.13±4.1	ns
	2000-2200	0.67±0.67	4.62±2.83	-	-	ns
	2200-2400	-	-	2.8±2.88	-	ns

Values followed by the same letter in a row are not significantly different at p<.05; or 0.001* significantly different at p< 0.05; ** significantly different at p=0.001 and ns denotes not significantly different.

number of mature trees compared with young individuals in Nigeria and West Africa, respectively. Similar lower young population was reported elsewhere by (Kirmse and Norton, 1984).

The mean tree height and trunk diameters were 7.3m ±0.54m and 30cm ± 0.03cm, respectively (n = 30). The canopy cover of the tree range between 3-5m with mean of 3.7m ±0.36m.

Effects of land use and altitude on stem number of *F. albida*

Within altitudinal zones, land use did not show significant influence ($P < 0.05$) on number of stems. However, in terms of absolute values, farmlands had higher stem number of 10.04±2.44 per ha followed by homesteads (9.26±3.04 per ha), grazing lands (6.25±6.25) and woodlots (4.13±4.1) at lower altitude zone. Similarly, in mid altitude farmlands contained higher individual *F. albida* trees (4.62±2.83 per ha) followed by homestead (0.67±0.67 per ha) while grazing land and woodlots did not contain any *F. albida* trees. On the high altidtude zone, overall lower number of stems (2.8±2.88 per ha) were found, and these are found on grazing land. There was no *F. albida* stem found in homestead, farmlands and woodlots at higher altitudin zone. This indicates the altitudinal stretch of the species does not go beyond the mid altitude range described in this study. Moreover, the observed lower proportion of growing population in all considered land use may be attributed interest of farmers to preserve only mature trees and to high grazing pressure, *F. albida* is highly palatable to all herbivores particularly for camel and goat. The tree being one of the few species with green foliage during the dry season the young seedlings and saplings may be readily eaten if not protected. Hence, the young seedlings should be protected from livestock trampling and human disturbance. Lower level awareness about the value of the *F. albida* may be contributing factors which is also agreed upon by farmers and development agents. On the other hand, altitudinal zone significantly affected the number of stems ($P < 0.05$). Higher number of *F. albda* stem (10.17±2.5 stem per ha) was found at lower altitudinal, the elast at higher altitudinal (0.93±0.9 stem

per ha) (Figure 4). The observed significant variation in stem number in response to altitudinal gradient could be explained by difference in temperature and soil fertility and moisture. Some of the interviewed farmers perceived that the growth of *F. albida* is slow in the upper altitude than lower altitude as results of cool temperature and poor soil fertility in upper altitude. The observed higher stem number may also be associated with associated vegetation and soil types. For example, higher number of stems was found under woodland vegetation and Vertisols at lower altitude compared to afromontane forest and cambisol at mid- and higher altitude (Table 4).

The measured density of *F. albida* in the study area also falls within the ranges of previous studies such as by Kamara and Haque (1992) who reported the average density of 6.52 trees/ha, and Poschen (1986) who reported the density range of 1-10 tree /ha, both in Ethiopia.

Perception of farmers on effects of *F. albida* on crop yield germination and population status

Out of the interviewed farmers (n=18), 60% perceived that *F. albida* might decrease crop yield underneath its canopy depending on crop types grown. The majority (10%) perceived that crop yield will decrease regardless of crop type, while about 30% perceive no difference under and outside the canopy. This finding is also supported by field observation. *F. albida* affects uniform germination of specific crops particularly crops such as maize and teff compared to wheat and barley. Similarly, farmers indicated that crop maturity differs under and outside the canopy; with those under the canopy maturing late compared to the crop outside the canopy. This may have to do with the shading effect of the tree as well as the associated higher soil moisture under the canopy. The presence excess OC may also favors vegetative growth at the expense of reproductive growth. Regarding threat to the tree species, despite the dominance of old diameter class, 100% of the respondent agreed that the tree would not face threat of disappearance in the future. This is justified by the fact that farmers cut only the branches rather than cutting if from the trunk. Multiuse nature of the tree has been
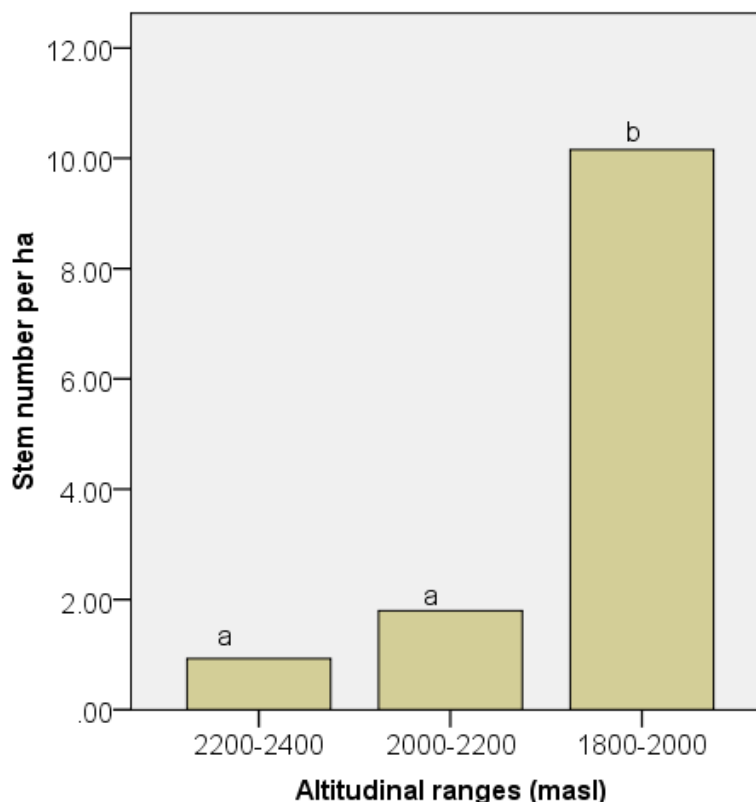
Figure 4. Stem number of *F. albida* in relation to altitude in Meskan District, Ethiopia.

emphasized the respondents for conserving it and caring for it by the interviewed farmers. All of the interviewed farmers confirmed the tree to provide diverse products such as fuel wood, fencing and livestock forage.

In general, based on interview, informal discussion and field observation, *F. albida* trees provide different ecosystem services such as increasing soil fertility, crop yield and biodiversity conservation. The tree also provide fuel wood, fencing and livestock forage. However, some ecosystem disservice was perceived by farmers , particularly depressing uniform germination of crop and crop yields particularly teff and maize if the canopy is left un lopped for more than 2 years.

The results of this study showed that significant differences in OM, OC and TN were observed between radial distances from *F. albida* trees while P, pH, MC, BD and C/N did not show any significant difference. Higher SOM, OC and TN were found in soils under the canopy of the trees compared with soil outside the canopy. Land use did not affect the distribution of *F. albida* while altitudinal zone significantly affected the distribution of *F. albida*. Higher number of stems were measured under farmlands at low altitude. The observed higher proportion

of mature individuals compared with lower proportion of young individuals signals the importance of planting new seedlings and protection of existing once from disturbance. Lower level of awareness about the ecological values of the *F. albida* may also be a contributing factor for decline of the population of the trees. The trees provide fodder for livestock feeding, fuel wood, fencing. It is obvious that a good stand of *F. albida* can be maintained only if rigorous and concerted efforts are made to plant and nurture the naturally growing trees. To keep the sustainability of this important multipurpose tree species, the following measures are recommend: the population of growing trees should be protected from livestock pressure and planting of new seedling in farmlands and closed area and degraded hillsides in order to conserve genetic pool of the species. The branches of the trees should be removed through pollarding for growing crops such as maize and teff in order to facilitate passages of light and rainfall for uniform germination under the canopy. Further research should be conducted in order to understand and select compatible annuals crops that could better grow under the canopy of trees.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

REFERENCES

Abebe N (2006). Status of soil fertility under indigenous tree canopies on farm lands in Highlands of Harargie, Ethiopia. MSc. Thesis, Haramaya University, Ethiopia.

Adamu GK (2012). Use of *Faidherbia albida* for soil improvement in small holder farming system of Gezawa Local Government Area of Kano State, Nigeria. Res. J. Environ. Earth Sci. 4(10):895-899.

Anderson JM, Ingram JSI (E.ds) (1993). Tropical soil biology and fertility, A hand book of Methods CABI publisher 2nd ed. P. 221.

Brady NC, Weil RR (2002). Nature and properties of soils. 13th Ed. New York, USA.

Buresh RJ, Tian G (2004). Soil improvement by trees in sub-saharan Africa. Agroforestry systems. Springer, Netherlands 38(1-3):51-76.

Hadgu KM, Kooistra L, Rossing WAH, Ariena HC, Van Bruggen AHC (2009). Assessing the effect of *Faidherbia albida* based land use systems on barley yield at field and regional scale in the highlands of Tigray, Northern Ethiopia. Food Sec. 1:337–350.
http://dx.doi.org/10.1007/s12571-009-0030-2

ICRAF (2000). Paths to prosperity through agroforestry. ICRAF's corporate strategy, 2001–2010. Nairobi: International Centre for Research in Agroforestry.

Jackson ML (1958). Soil chemical analysis. prentice; Halls, Inc., Englewood cliffs, New Jorsey. Sixth printing. P. 498.

Jiregna G, Rozanov A, Legesse N (2005). Trees on farms and their contribution to soil fertility parameters in Badessa, eastern Ethiopia Biol. Fertil. Soils 42:66–71.
http://dx.doi.org/10.1007/s00374-005-0859-2

Kamara CS, Haque I (1992). *Faidherbia albida* and its effects on Ethiopian highland Vertisols. Agrofor. Syst. 18:17-29.
http://dx.doi.org/10.1007/BF00114814

Kindya G (2004). Dry land Agroforestry Strategy for Ethiopia. Paper Presented at the Drylands Agroforestry Workshop. 1st-3rd September 2004. ICRAF Headquarters, Nairobi- Kenya.

Kirmse RD, Norton BE (1984). The potential of *Acacia albida* for desertification control and increased productivity in Chad. Biol. Conserv. 29:121-141.
http://dx.doi.org/10.1016/0006-3207(84)90073-9

Manjur B, Abebe T, Abdulkadi A (2014). Effects of scattered *F. albida* (*Del*) and C. macrostachyus (Lam) tree species on key soil physicochemical properties and grain yield of Maize (*Zea mays*): a case study at umbulo Wacho watershed. Southern Ethiop. J. Agric. Res. 3(3):063–073.

Mokgolodi NC, Moffat PS, Ling-ling SHI, Yu-jun L, Chao M (2011). Achieving food and nutritional security through agroforestry: a case of *Faidherbia albida* in sub-Saharan Africa 13(2):123-131.

Olsen SR, Summer LE (1982). Methods of soil analysis; part 2. Chemical and microbiological properties of Phosphorus. ASA Monograph number. 9:403-430. paper No.17. World Bank, Washington D.C. P. 48.

Phombeya HSK, Simmons E, Giller KE (2005). Farmers' perception of the value of *Faidherbia albida* trees in the farming system of Central Malawi.

Poschen P (1986). An of the *Acacia albida*- based agroforestry practices in the Hararghe highlands of eastern Ethiopia. Agrofor. Syst. 4:129-143. http://dx.doi.org/10.1007/BF00141545

Rhoades C (1995). Seasonal pattern of nitrogen mineralization and soil moisture beneath *Faidherbia albida* (syn *Acacia albida*) in central Malawi Agrofor. Syst. 29:133-145.
http://dx.doi.org/10.1007/BF00704882

Saka AR, Bunderson WT, Itimu OA, Phombeya HSK, Mbekeani Y (1994). The effects of *Acacia albida* on soils and maize grain yields under smallholder farm conditions in Malawi. For. Ecol. Manage. 64:217-230. http://dx.doi.org/10.1016/0378-1127(94)90296-8

Sanda AR, Atiku M (2013). Effect of *Faidherbia albida* on soil nutrients management in the semi-Arid Region of Kano State. Nigeria IJSTR. 2(7):201-203.

SPSS Inc (2006). Statistical Package for Social Sciences for Windows. Release 20.0.0. SPSS Inc. Chicago.

Vetaas OR (1992). Micro-site effects of trees and shrubs in dry savannas. J. Veg. Sci. 3:337-344. http://dx.doi.org/10.2307/3235758

Walkley A, Black C (1934). Examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Yadessa A, Itanna F, Olsson M (2009). Scattered trees as modifiers of agricultural landscapes: the role of waddeessa (*Cordia africana* Lam.) trees in Bako area, Oromia, Ethiopia. Afr. J. Ecol. 47 (1):78–83.
http://dx.doi.org/10.1111/j.1365-2028.2008.01053.x

Yeshanew A (1997). The contribution of trees to soil chemical properties in Croton machrostachyus-based indigenous agroforestry system. Ethiopian MSc in Forestry Programme Thesis Works Report No. 1997:28. Skinnskateberg, Sweden.

Zar JH (1996). Biostatistical Analysis. 3rd edn. Prentice-Hall International Inc, Upper Saddle River, NJ, USA.

Full Length Research Paper

Evaluation of wheat cultivars for slow rusting resistance in Guji zone, Southern Oromia

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Evaluation of Eleven and local bread wheat cultivars evaluated for slow rusting resistance was conducted in Bore district of southern Oromia during the main cropping season of 2011 under natural epidemics at Bore Agricultural Research site. Field evaluation of slow rusting resistance was assessed through Incidence, disease severity (DS), AUDPC and rAUDPC. Results of mean comparison of final rust severity, AUDPC and rAUDPC indicating that the cultivars; PBW343, Kubsa, Hawi, local and Galema had highest final rust severity (FRS) and rAUDPC and susceptible infection (4) at the later growth stage. Shorima, Danda`a, Kakaba, ET13A2 and Digalu had moderately resistance to moderately susceptible infection type at later growth stage. However, disease development on this cultivar was very slow compared to the highly susceptible cultivars. That why these cultivars had low disease severity, low AUDPC and rAUDPC, that is, up to 70% of susceptible cultivars and they could have probably slow rusting resistance. Cultivar ETBW5496 had no any infection and thus selected as immune or resistance cultivar.

Key words: Slow rusting, rAUDPC, Oromia.

INTRODUCTION

Wheat (*Triticum aesvivum* L.) is one of the major cereal crop cultivated in Ethiopia. However, productivity of wheat in Ethiopia in general and southern Oromia in particular is very low. The low productivity is attributed to a number of factors including biotic (diseases, insects, and weeds), abiotic, and low adoption of new agricultural technologies. Among these factors, wheat stem rust, caused by Puccinia pers.f.sp.tritici Eriks and E.Henn, is one of the most destructive diseases of wheat worldwide in general and particular in Ethiopia. In Ethiopia wheat

stem rust cause a complete annihilation of wheat crops over wide areas during epidemic years. Slow rusting resistance is one of the methods used for wheat stem rust management during the epidemic years. Since race-specific resistance may be overcomed through genetic shifts or new form of virulence in the pathogen population, durable resistance is of great interest to wheat breeders (Suenaga et al., 2001; Lal ahamed et al., 2004). Slow rusting wheat cultivars infected with *Puccinia graminis* exhibit longer latent period, low rate of disease

development than the susceptible wheat cultivar even though they are infected by the rust disease under the same environmental condition and disease pressure. The latent period is one of the important component of slow rusting resistance. In Ethiopia little effort was made so far to evaluate slow rusting resistant under natural condition and slow rusting as specific management option was not fully understood. However, the present paper was therefore, designed to evaluate wheat cultivars/ lines for slow rusting. The study reports the finding of study which is carried out to assess the slow rusting of 13 bread cultivars/line.

The objective of the study is to evaluate bread wheat cultivars for their slow rusting resistance response under field condition at Bore

MATERIALS AND METHODS

Eleven released bread wheat cultivars were planted along with one local check for their slow rusting ability under bore field condition at Bore Agricultural Research Center (BARC). The experiment was laid out in randomized complete block design (RCBD) with three replications. A plot size of 2.5 m × 1.2 m and 20 cm between rows was used respectively. A universally susceptible variety (Morocco) was planted around the whole experimental area to ensure sufficient disease pressure and uniform inoculum load around the whole experimental work. No artificial inoculation was made for the experiment. Initial disease assessment was made immediately after 50% of disease symptom observed on local or susceptible cultivar (Appendix Table 1).

Disease data collections

The disease severity was recorded as percentage of leaf/ stem area covered by rust following modified Cobb's scale as developed by Peterson et al. (1948). According to this scale, at 100% disease severity, the actual leaf/stem area covered by rust pustules is 37%. Wheat stem rust severity was examined visually on the whole plants and recorded as the percentage of plant part (tissue) affected. Disease assessment was commenced at 96 days after sowing (DAS) on this day 50% of susceptible cultivar shows disease symptom and continued to 140 DAS (maturity) at interval of 10 days from pre- tagged 10 plants from each four center row each plot/cultivars per blocks. Disease incidence (DI) was computed as proportion of infected plant to the total number of plant in assessed from each cultivar and it calculated as follows:

$$DI = \frac{Number\ of\ diseased\ plant}{Total\ number\ of\ plant\ assessed} \times 100$$

Percent severity index (PSI) was used to convert the scaled based collected severity into percentage by using the formula developed by Wheeler (1969).

$$PSI = \frac{Sum\ of\ material\ rating}{Numbers\ of\ plant\ scored\ \times\ maximum\ score\ on\ the\ scale} \times 100$$

Disease progress rate ('r'): Transformed percent disease severity at different date of assessments was linearized by logistic (ln(Y/ (1-Y) (Vander Plank 1963). The model was selected based on the R square value. The linearized data were regressed over time to determine the disease progress rate of each cultivar.

Area under Disease Progress Curve (AUDPC): The area under disease progress curve (AUDPC) was calculated by using the formula suggested by Wilcoxson and kovmand. (1975).

$$AUDPC = \sum_{i=1}^{n} [(X_{i+1} + X_i/2)] \times (t_{i+1} - t_{i)}$$

Where, X_i = the average coefficient of infection of ith record; X_{i+1} = the average coefficient of infection of $i+1^{th}$ record and $t_{i+1}\_t_i$ = Number of days between the ith record and $i+1^{th}$ record and n = number observations.

Relative Area under Disease progress curve (rAUDPC):

$$rAUDPC = \frac{AUDPC\ of\ cultivars}{AUDPC\ of\ local\ or\ susceptible\ cultivar} \times 100$$

Lesion length: lesion was measured randomly by centimeter from one edge of the lesion zone to the other. Five lesion per plant and 25 lesion per plot or cultivars were measure and the average was used for the analysis.

Infection type: Infection type was collected based on the original scale proposed by Stakman et al. (1962).

Data analysis

Data on wheat stem rust incidence, severity, and AUDPC and disease progress rate were subjected to analysis of variance by using the methods described by Gomez and Gomez (1984) using SAS computer soft ware. Mean separation was based on LSD at 5% level probability level. Square root transformation was done for the disease progress rate computation to minimize variation due to many zeros during the disease assessment.

RESULTS AND DISCUSSION

Stem rust incidence

Final disease incidence of cultivars showed that there was a highly significant variation among evaluated cultivar at (p < 0.01). However, no significance difference was observed for Danda`a, Hawi, Digalu, Kubsa, Galema, Galil, Local and PBW 343, but difference were significant for all the rest of the cultivars. At the later growth stage all cultivars were susceptible to the disease except ETBW 5496 and Shorima. This cultivars show a resistant reaction throughout the disease assessment. The onset of the disease was earlier for the Kubsa, PBW 343, Hawi and Galema. Delay onset was observed by Shorima (ETBW5483), Danda`a (Danphe #1), Kakaba (Picaflor #1), ET13A2 and Digalu (HAR 3116). This indicating that the evaluated cultivars were varies in their level of disease resistance and disease development. The disease incidence was ranging from 0% (for resistant cultivar), moderate for slow rusting and 100% (for highly susceptible) cultivars. Initial incidence seemed to have little or no effect on the final severity of the cultivars. For example, in this study the local cultivars had only 0% initial incidence at the first disease assessment (96 DAS). However, the highest final severity of 91.7% was recorded from this cultivar. On the other hand, variety

Galil, which had initial incidence of 13.33%, had final severity of 60.83% which was moderately resistance cultivars.

Rust severity

No cultivar showed hypersensitive reaction at field condition; however, very low level to high disease severity was recorded from the evaluated cultivars indicating high level of slow rusting resistance as compared to local check. Disease severity of cultivars was showed highly significant at (P< 0.01). The final stem rust severity was varying from 0 to 93.67% for ETBW5496 and local respectively. Digalu, ET13A2, Danda`a and Galil were not significantly different from each other.

Previous studies also showed that final disease severity is one of the parameter which can be used to measure the resistance levels along with other slow rusting parameters (Parlevliet and van Ommeren, 1975; Li et al., 2006).

Final disease severity up to 93.67 was recorded for local, followed by Hawi (92.67%), Kubsa 91.33%), PBW343 (90.17%) and Galema (79.667) were grouped as highly susceptible cultivar depend their severity and infection type, while ETBW5496 remain immune throughout the disease assessment. Based on final stem rust severity cultivars were grouped into three ranges, that is, 0-30, 31-70 and greater than 70%. Four cultivars among the evaluated cultivars (that is, Hawi, Kubsa, PBW343 and Galema) were having maximum final wheat stem rust severity more than 70% of the check. Two cultivars (ETBW5496 and Shorima) exhibited disease severity up to 30% of the check and were marked to be having better resistance. Five cultivars (Kakaba, Danda`a, Digalu, ET13A2 and Galil) displayed relative final disease severity up to 70% of check and marked to be moderately resistant. Final rust severity represents the cumulative result of all resistance factors during the progress of epidemic (Parlevliet and van Omeren, 1975). Previously, Herrera-Foessel et al. (2007) also used final rust severity as a parameter to assess slow rusting behavior of wheat breeding lines. And confirmed lower final rust severity value for durum lines exhibiting slow rusting resistance as compared to local check.

Similarly, Broers et al. (1996) and Ali et al. (2009) also carried out field assessment of partial resistance to yellow rust for ranking of lines. According to them resistance level based on disease severity along with other slow rusting resistance parameters, they found that resistance level ranged from very low to very high among the tested cultivars. ETBW5496 showed immune rust reaction throughout the disease assessment. This cultivar might have a combination of many major gene or minor genes which gives highest protection to wheat stem rust.

According to results of other researchers (Ali et al.,

2007) lines which had resistance reaction at adult plant stage and low values of slow rusting parameters may probably carry major gene or combination of major genes based resistance, effective against all virulence used. The current studies corroborate results of those researchers.

Disease progress rate

Logistic model was used to describing the rate of stem rust infection. The coefficient of determination (R^2) was higher for logistic model. Based on logistic model, the regression equation used to describe the rate of wheat stem rust progress was not significant for all cultivars except for the susceptible cultivar apparently because of low disease development per unit day on slow rusting cultivars. The coefficient of determination (R2) was very low (<42%) for each plot of slow rusting cultivars. However, in most of susceptible cultivars the disease progress rate was significant at (P<0.05). Generally, variation in wheat stem rust infection rate due to the resistance level of the cultivar was clearly observed. Wheat stem rust was increasing more rapidly on susceptible plots than on slow rusting cultivars (Appendix Table 2).

Area under the disease progress curve

The PBW 343 reached highest AUDPC (1749% days) which was not significantly varied from Kubsa, Hawi and local but, significantly different from other susceptible cultivars.

Based on the relative AUDPC values, cultivars were categorized into two distinct groups that is, those exhibiting relative AUDPC values up to 30% of local and those showing relative AUDPC value up to 70% of local.

Six cultivars namely: ETBW5496, Shorima, Danda`a, Kakaba, Digalu and ET13A2 exhibited relative AUDPC values less than 30% of local and were marked to be having better level of slow rusting. Galil had a relative AUDPC values up to 70% of local check was grouped as moderately slow rusting. Five cultivars namely, Galema, Kubsa, Hawi, Local and PBW343 had a rAUDPC value greater than 70% of the local were classified as susceptible to highly susceptible.

Previously, Broers et al. (1996) has also evaluated wheat lines for their slow rusting ability through AUDPC and found that resistance levels ranged from very low (in Taichung 23) to very high (in Parula) among the tested lines. That why, the AUDPC and others parameters values were used as a classification criterion

The resistant cultivar in this study was found to be ETBW5496. This cultivar also gave medium yield, the lowest severity and lowest AUDPC throughout the disease assessments. From the evaluated cultivars

Shorima, ET13A2, Kakaba, Danda`a, and Digalu were good slow rusting as they had low disease severity and low AUDPC as compared to others while Galil were classified under moderately susceptible (Appendix Table 2).

SUMMARY AND CONCLUSION

Eleven bread wheat cultivars released by the Kulumsa Agricultural Research Center (KARC) and one local were evaluated for slow rusting against wheat stem rust under field conditions. The evaluations of slow rusting cultivars were based on AUDPC, rAUDPC, and final stem rust severity. These cultivars showed varying levels of resistance against wheat stem rust in natural conditions at Bore district of the Guji zone. Based on slow rusting parameters three groups of cultivar were identified. Namely PBW 343, Kubsa, Hawi, Local and Galema were classified as highly susceptible. However, ETBW5496 and Shorima showed better resistance cultivar. ET13A2, Danda`a, Kakaba, Digalu, and Galil were classified as moderately slow rusting. Highest yield was obtained from the slow rusting cultivars Digalu (7.39t/ha).

Based on these findings of the study, it can be concluded that wheat stem rust is an important disease that requires better attention in the area in terms of disease management. Use of slow rusting cultivars and replacing local and susceptible improved cultivar like Kubsa with slow rusting cultivars is important. ETBW5496 appears to have better resistance to the wheat stem rust and is a promising cultivar since the yield was also far better than the local. The results of current field experiment showed that the cultivars had diversity regarding resistance reaction, ranging from complete resistance to susceptible lines. This creates an opportunity for further improvement of resistance level of wheat cultivars and future manipulation in wheat improvement programs after confirmatory study. Finally in Guji as well as where ever wheat stem rust was existed planting of slow rusting cultivars is a simple solution for the management of the disease.

Conflict of Interest

The author(s) have not declared any conflict of interest.

REFERENCES

Ali S, Shah SJ, Ibrahim M (2007). Assessment of wheat breeding lines for slow yellow rusting (Puccinia striiformis West. tritici) Pak. J. Biol. 10(19):3440-3444. http://dx.doi.org/10.3923/pjbs.2007.3440.3444

Broers LHM, Subias XC, Atilano RML (1996). Field assessment of quantitative resistance to yellow rust in ten spring bread wheat cultivars. Euphytica 90:9-16.

Gomez KA, Gomez AA (1984). Statistical procedure for agricultural research 2nd ed . John Wiley and Sons. New York.

Herrera-Foessel SA, Singh RP, Huerta-Espino J, Crossa J, Djurle A, Yuen J (2007). Evaluation of slow rusting resistance components to leaf rust in CIMMYT durum wheats. Euphytica 155:361-369.

Lal Ahamed M, Singh SS, Sharma JB, Ram RB (2004). Evaluation of inheritance to leaf rust in wheat using area under disease progress curve. Hereditas 141:323-327. http://dx.doi.org/10.1007/s10681-006-9337-7

Li ZF, Xia XC, Zhou XC Niu YC, He ZH, Zhang Y, Li GQ, Wan AM, Wang DS, Chen XM, Lu QL, Singh PL (2006). Seedling and slow rusting resistance to stripe rust in Chinese common wheats. Plant Dis. 90:1302-1312. http://dx.doi.org/10.1094/PD-90-1302

Parlevliet JE, van Ommeren A (1975). Partial resistance of barely to leaf rust, Puccinia hordei, II Relationship between field trials, micro plot tests and latent period. Euphytica 24:293-303. http://dx.doi.org/10.1007/BF00028194

Peterson RE, Campbell AB, Hannah AE (1948). A Diagrammatic scale for estimating rust intensity of leaves and stems of cereals. Canad. J. Res. (C), 26:496-500. http://dx.doi.org/10.1139/cjr48c-033

Stakman EC (1968). What are the prospects for development of stem rust. Ann. Appl. Biol. 80:275-281

Vander plank JE (1963). Plant disease: Epidemics and control. Academic press, new work.

Wheeler BEL (1969). An Introduction to Plant Diseases. John Wiley and Sons Ltd., London, United Kingdom P. 301.PMid:5787744

Wilcoxson RD, kovmand BS, Atif HA (1975). Evaluation of wheat cultivars for Ability to retard development of stem rust. Ann. Appl. Biol. 80:275-281. http://dx.doi.org/10.1111/j.1744-7348.1975.tb01633.x

APPENDIX

Appendix Table 1. Description of bread wheat cultivars used for evaluation of slow rusting resistance.

No.	Cultivar	Pedigree	Year of release	Maturity (days)	Adaptation zone	Source center
1	Danda`a	Kiritati//2*PBW65/2*Seri.1B	2010	110-145	2000-2600	KARC/EIAR
2	ETB13A2	UQ105 Sel X ENKOY	2007	118-127	1890-2800	ADARC
3	Digelu	Sha 7 / Kauz	2005	100-120	2000-2600	KARC/EIAR
4	ETBW 5496	UTQE96/3/PYN/BAU//Milan	2011	NA	NA	ICARDA
5	Galema	4777(2)//FKN/GB/3/PVN	1995	NA	2200-2800	KARC/EIAR
6	Galil	NA	2010	NA	NA	Hezera genetic ltd
7	Hawi	CHIL/PRL	2000	105-125	1800-2200	KARC/EIAR
8	Kakaba	Kititati//Seri/Rayon	2010	90-120	1500-2200	KARC/EIAR
9	Kubsa	ATTILA	1995	NA	2000-2600	KARC/EIAR
10	Local	NA	NA	NA	NA	farmer
11	Shorima	UTQE96/3/PYN/BAU//Milan	2011	NA	NA	ICARDA
12	PBW343	NA				

KARC/EIAR = Kulumsa Agricultural Research Center/Ethiopian Institute of Agricultural Research; ADARC/ARARI = Adet Agricultural Research Center/Amhara Regional Agricultural Research Institute; NA = not available.

Appendix Table 2. Wheat stem rust disease incidence, severity, area under the disease progress curve, relative area under the disease progress curve of 13 bread wheat cultivar at Bore during main season of 2011.

Cultivar	% Incidence	%Severity	AUDPC	rAUDPC	LL (cm)	Dpr
Danda`a	83.33[ab]	48.33[bc]	190[ef]	11.19	0.193[e]	0.006
ETB13A2	46.00[c]	48.00[bc]	296.67[de]	16.95	0.067[e]	0.005
Digelu	90.00[ab]	50.67[bc]	317.17[de]	18.68	0.360[e]	0.006
ETBW 5496	0.00d	0.00[e]	0.00[f]	0.00	0.000[e]	0.000
Galema	100.00[a]	79.67[a]	1504.67[b]	85.99	1.413[ab]	0.06
Galil	93.33[ab]	55.16[bc]	660.5[c]	38.97	0.760[d]	0.010
Hawi	100.00[a]	92.67[a]	1698.67[a]	100.00	1.132[bc]	0.090
Kakaba	70.00b[c]	45.00[c]	192.67[ef]	11.35	0.117[e]	0.008
Kubsa	100.00[a]	91.33[a]	1682.00[ab]	99.10	1.530[a]	0.101
Local	100.00[a]	93.67[a]	1697.2[ab]	100.00	1.550[a]	0.08
Shorima	1.50[d]	7.00[e]	29.25[f]	9.85	0.000[e]	0.004
PBW343	100.00[a]	90.17[a]	1749.8[a]	103.09	1.367[ab]	0.101
LSD(0.05)	26.124	14.16	197.95	-		0.006
CV (%)	20.34	14.25%	14.34		18.84	0.006
R2						89.77%

Means with the same letter are not significantly different from each other. Inc = incidence and AUDPC = Area under the disease progress curve; rAUDPC = relative area the under disease progress curve, average coefficient of infection; I = immune; MR = moderately resistance; MS = moderately susceptible; MSS = moderately susceptible to susceptible; S = susceptible; LL = lesion Length; DPr = disease progress rate.

Full Length Research Paper

Scenario-based simulations of the impacts of rainfall variability and management options on maize production in Benin

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Many studies have dealt with crop production under climate change projections in sub-Saharan Africa, focusing on average long term trends over time-windows of five to twenty years. The efforts undertaken in this study rather combine effective farm management/abiotic factors (e.g., soil tillage, sowing date, fertilizer use, soil fertility status) with variabilities in rainfall conditions at decadal scale to simulate rainfed maize yield in Benin (West Africa). To achieve this goal, the model system Environmental Policy Integrated Climate (EPIC) was used. Management options such as fertilizer use and sowing date scenarios were considered. Variability in rainfall conditions were considered to account for extremes in yield production. Changes in plant growth limiting factors such as water stress and nitrogen stress were conjointly analyzed to account for not only the effects of climate changes, but also soil fertility status and various pressures on the land resources. Excluding catastrophic factors such as floods and pests the results indicate yield production ranges of about 500 to 1400 (±250) kg ha^{-1} a^{-1} in the North and 1100 to 2300 (±300) kg ha^{-1} a^{-1} in the South of the investigated region. The impacts of sowing date on the production were within comparable magnitudes of that of climate changes/ rainfall variability (up to - 50% of the yield in the North). Higher yield production was globally associated with earlier sowing date referring to the period 2000 to 2009, while associated with later sowing dates referring to period 2010-2050. Moreover, higher water stress is associated with earlier sowing dates, while higher nitrogen stress is associated with later sowing dates referring to the period 2010 to 2050. Shifting towards late sowing dates corresponding to a cumulated rainfall of 180 mm may reduce water stress and make efficient use of fertilizers in future (2010 to 2050), regardless high or low annual rainfall.

Key words: Maize yield, sowing date, fertilizer use, rainfall variability, climate change impacts.

INTRODUCTION

Benin is not classified at the same vulnerability level as the sahelian countries, but is highly dependent on the agricultural sector, which determines the economic development of the country (Kuhn et al., 2010). Up to a recent past a stable yield production in Benin is mainly the results of shifting agriculture based on fallow

systems, without the use of fertilizers. The country is characterized by harsh climatic conditions, high rainfall intensities, prolonged dry seasons, extensive drought periods, high population growth, and the excessive use of resources (Heldmann and Dovenspeck, 2008; Hiepe, 2008; Gaiser et al., 2011; Bossa et al., 2012b, Bossa and Diekkrüger, 2012). Compared to temperate regions, the decline in food productivity since the 70s is drastic due to the climate condition, low soil fertility, and the poor quality of the subsoil and unstable soil properties (Hiepe, 2008; Bossa et al., 2012b). Some regional climate models predict a decrease in annual rainfall up to 30% by 2050 with a significant within-region differences (Paeth et al., 2008). This change will decrease yield production already challenged by low knowledge of efficient agricultural management. Although it is well known that yield reduction could be compensated by fertilizer availability and use, without exact knowledge of the reduction mechanism, adaptation and resilience measures are less efficient.

Variability in food availability may be seen as the results of complex interactions between a large number of process factors (Diepen and van der Wall, 1996) and different sources of climate variability (IPCC, 2001): (1) abiotic factors, such as soil moisture, soil fertility, weather; (2) farm management factors, such as soil tillage, sowing date, fertilizer use, irrigation; (3) socioeconomic factors, such as population pressure, education levels; (4) catastrophic factors, such as droughts, floods, and pests; and (5) changes in the mean annual rainfall or/and spatial/intra-seasonal patterns. Climate change increases the variability of rainfall in many parts of the world. This will be a critical concern for Benin, whose food security is essentially based on rainfed agriculture. Rainfall variability and mean effects of climate changes are already shown as the highest potential risk for food security in Benin (Paeth et al., 2008; Speth et al., 2010; Agbossou et al., 2012), but this still needs to be regionally nuanced due to combined effects of large variability in the intra-seasonal rainfall pattern, large variability in the abiotic factors (soil fertility status), uncertainties concerning the onset of the rainy seasons (sowing date), and variability in fertilizer use as well as tillage techniques. A clear consideration of all these aspects in the simulation models may be seen as relevant assets to support specified adaptation and resilience measures under different conditions at the regional scale.

Lacatusu and Lacatusu (2011) combined field and laboratory description of abiotic factors to suggest a complex indicator for assessing soil fertility using two groups of potentiating and penalty indicators. They included in the first category climatic indicators (mean precipitation and temperature), the nutritive spaces, water and air regime (edaphic volume, and gleization level), physical indicators (texture, bulk density), chemical indicators (pH, humus content and the content of macro elements). The second category includes levels of salinization, alkalization, carbonation, pollution and artifacts content. It was a successful approach that may be associated with the simulation efforts to account for the prediction uncertainties and the significance of soil fertility effects while attempting to quantify the impacts of climate changes on yield production. Many studies have shown the importance of planting date for agricultural management (Stern et al., 1981; Mandal et al., 2005; Baldwin and Cossar, 2009; Egli and Cornelius, 2009). The sowing date determines moisture availability through the growing season as well as the schedule of management practices such as tillage and fertilizer use. Planting too early might lead to crop failure and planting too late might reduce valuable growing time and crop yield, but there is still no consensus in literature about the question of how much rain over which period defines the onset of the rainy season for agro-climatological impact studies (Laux et al., 2010). Inter-annual variable and spatially distributed planting dates may be developed on the basis that wet season starts when, for the first time after March 1st, 25 mm of rain falls within 2 consecutive days, and no dry period of 10 or more days occur in the following 30 days (Stern et al., 1981; Kiniveton et al., 2009; Laux et al., 2008, 2010). Ati et al. (2002) as well as Ndomba (2010) mentioned that such criteria are rather useful for retrospective analysis but not for guiding farmers in a particular year. Ilesanmi (1972) successfully used cumulated percentage mean rainfall (7 to 8%) to derive the onset of the rainy season. It is a commonly used approach, mathematically elegant, efficient, free of assumptions, and relying only on rainfall data rather than the mere inferential methods (Olaniran, 1983; Odekunle et al. 2005; Odekunle, 2006; Ndomba, 2010). For Burkina Faso, Waongo et al. (2014) showed that a Fuzzy Rule based approach is helpful for determining optimal sowing date and that yield may increase by 20%. For their regional scale study, the General Large-Area Model for Annual Crops was used.

This study rather used early and late sowing dates derived from cumulated rainfall amount of 100 and 180 mm counting from the first day of the year, to better discuss the impacts of scenario-based rainfall conditions on maize production.

The study analyzed at a regional scale the spatial limitations of maize production under different conditions of climate changes, agricultural management, soil fertility status and planting dates. The aim of the study was to use the agro-ecosystem model Environmental Policy Integrated Climate (EPIC) to answer the following questions: (1) are there any regional differentiations in maize production in Benin? (2) How significant are the influences of management practice and fertilizer use on maize yield? (3) What are the changes in maize production under climate change up to 2050? (4) Under climate change conditions are water and nitrogen stress the limiting factors for maize production? Are there any
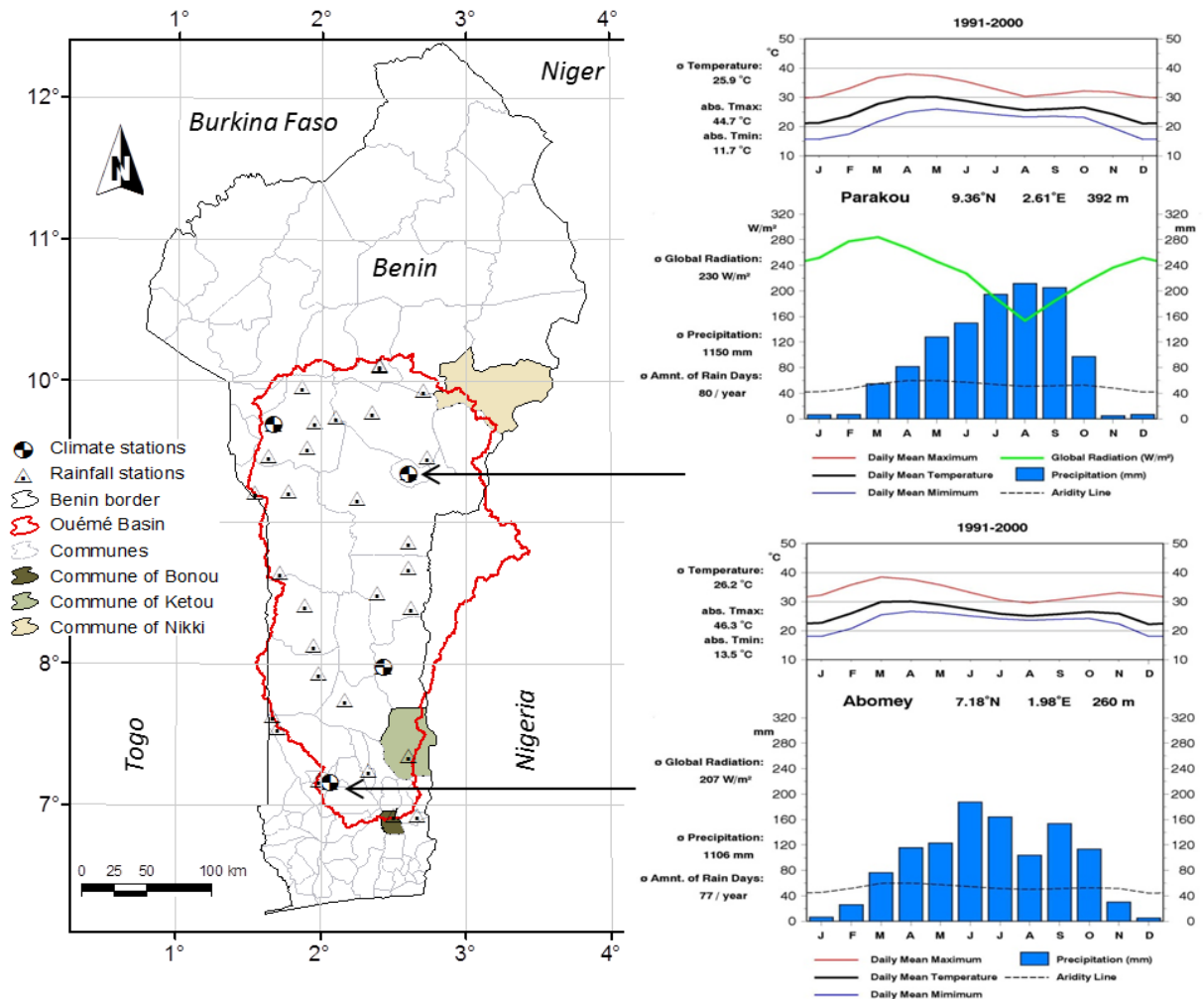
Figure 1. Study area and location of the three communes. Climate diagrams of the North (Soudanian climate) and South (Guinean coast) of the Ouémé catchment (after Speth et al., 2010).

regional differentiations? (5) Are there any potential management responses to constrain the effects of climate change on maize production?

MATERIALS AND METHODS

Study area

Benin is located in the West of Africa, between Togo and Nigeria (Figure 1) with an economic situation entirely based on agriculture, forestry and fisheries (Kuhn et al., 2010c). Compared to other countries located at the same geographical latitudes Benin records up to 400 mm less precipitations, because of the Dahomey gap anomaly. During the year the region is successively influenced by the humid monsoon air and the dry and hot harmattan. Situated in the wet (Guinean coast) and the dry (Soudanian zone) tropical climate, the Ouémé catchment (as considered in this work) (Figure 1) records annual mean temperatures of 26 to 30°C, annual mean rainfalls of 1,280 mm (from 1950 to 1969) and 1150 mm (from 1970 to 2004) at the climatic station of Parakou (cf. Figure 1) (Speth et al., 2010). As shown in Figure 1, the Soudanian zone has a

unimodal rainfall season that starts in April and peaks in August whereas the Guinean zone exhibits a bimodal rainfall season that starts in March and peaks in June and October (Fink et al., 2010). A complex rainfall pattern is observed within the study region. Indeed, it was shown that the daily rainfall accumulation at one location may surpass 150 mm (corresponding to roughly 8% of mean yearly accumulation), with 80 mm falling within two hours, while slight or no rainfall may occur at a point only 20 km away from that location (Diederich and Simmer, 2008). At regional scale, predominant soils are fersialitic soils (ferruginous tropical soils), characterized by clay translocation and iron segregation (ferruginous tropical soils with concretions), which lead to a clear horizon differentiation (Faure and Volkhoff, 1998; Gaiser et al., 2010a; Bossa, 2012). A local scale description has shown a typical catena with soils formed on the slopes, leached ferruginous tropical soils (Orthidystri-Epi- or Endoskeletic Acrisols/Haplic Lixisols or Typic Kandi-ustults/Typic Kandiustalfs) (Busche et al., 2005; Junge, 2004; Sintondji, 2005; Hiepe, 2008; Gaiser et al., 2010a; Bossa et al., 2012a,b). Leached and indurated ferruginous tropical soils (Hyperalbi-Petric Plinthosols/Plinthic Petraquepts) are developed at lower parts of the slopes. Hydromorphic soils (Humic Gleysols/Typic Epiaquepts) are found in the inland valleys. In the riverbeds, poorly evolved soils are distributed (Arenic Fluvisols/Typic Ustifluvents) (Junge, 2004;

Sintondji, 2005; Hiepe, 2008; Gaiser et al., 2010a; Bossa et al., 2012a,b).

Different types of savannahs and agricultural lands dominate the landscape in Benin. Whereas the South of the country is already stamped by agriculture, the remaining natural vegetation in the Northern regions is converted step by step to agriculture (Wezel and Böcker, 2000). Maize constitutes the most important crop and one of the main staple foods. Despite the increasing maize production in central- and Northern Benin, the South still accounts up to 60% of total maize production in Benin (van den Akker, 2000). Usually shifting agriculture with fallow systems is used to regenerate soil fertility. Due to very low degree of mechanization, tillage is only possible with traditional hand tools and man power. Irrigation and fertilizer use are still weak in Benin. Furthermore, the amounts of fertilizer usually applied are under strict policies (Kuhn and Gruber, 2010). This study concentrates on three communes/localities indicated in light-brown, light-green and dark-green within the Ouémé catchment (Figure 1): (1) Nikki (light-brown), North of the Ouémé catchment; (2) Ketou (light-green) in the South; and (3) Bonou (dark-green), also in the South of the catchment.

Modeling approach

The EPIC (Williams et al., 1989) is an agro-ecosystem model able to calculate crop growth under different environmental conditions. It takes into account all relevant processes required for simulating maize production and has already been successfully applied in Benin (Gaiser et al., 2010b). In addition it allows the evaluation of crop growth stress factors including water stress, nitrogen stress, temperature stress which are very important for discussing the limitations of the production at a specific location. Besides maize, EPIC is suitable for many other crops. EPIC is a field scale model using a daily time step and allows long term simulation up to hundreds years. Although there is already an update version, in this study the version 3060 is used due to technical consideration concerning manual fertilizer application. To represent the important processes for crop growth, EPIC contain eight sub-models accounting among others for weather, soil and hydrological processes (Williams 1995; Williams et al., 2006). The crop growth is calculated through the leaf area development, the light interception and the conversion into biomass. Biomass is therefore estimated with the Monteith´s approach (Monteith, 1977) which is indicated through Equation (1).

$$\Delta B_{p,i} = 0.01 \times WA \times PARi \tag{1}$$

Where, $\Delta B_{p,i}$ is the potential increase in biomass in kg ha^{-1} in day i, WA is the Biomass-energy ratio describes the conversion of energy to biomass in (kg ha^{-1})(MJ m^{-2})$^{-1}$, $PARi$ is the photosynthetic active radiation in MJ m^{-2}d^{-1}.

Only maize yield is simulated in this study as amount of economic dry yield (kg ha^{-1}), estimated in EPIC through the harvest index Equation (2):

$$YLD = HIA \times B_{AG} \tag{2}$$

Where, YLD is the amount of dry and economic useful yield in kg ha^{-1}, HIA is the adjusted (water stress reduced) harvest index and B_{AG} is the cumulative above-ground biomass (kg m^{-2}) before senescence occurs.
The harvest index is calculated using Equation (3)(Williams et al., 1989):

$$HI_i A = HI_{i-1} A - HI \left(\frac{1}{1 + WSFY \times FHU_i (0.9 - WS_i)} \right) \tag{3}$$

Where, HI is the potential harvest index on the day of harvest and is defined as the ratio of harvestable yield to total aboveground biomass), *WSFY* is the crop parameter expressing the sensitivity of harvest index to drought, *FHU* is the crop growth stage factor, WS is the water stress factor, i and i-1 are the Julian days of the year.

Crop growth is limited through stress factors if their values are below 1. In EPIC five stress factors could constrain the daily increase in biomass production. These five factors include water stress, temperature stress, nitrogen stress, phosphor stress and aeration stress. For our work only water and nitrogen stress are interesting. Water stress is calculated through supply and demand, occurring when demand is higher than supply controlled by available water in the soil Equation (4):

$$WS_i = \frac{\sum_{\ell=1}^{M} u_{i,\ell}}{E_{Pi}} \tag{4}$$

Where, *WS* is the water stress, *u* is the water use in horizon ℓ, *Ep* is the potential water use of plant on day *i*.
Nitrogen stress is calculated similarly to water stress, considering also supply and demand. The accumulated nitrogen content of the plant is compared with optimal nitrogen content (Williams, 1995). All stress factors are indicated through stress days, without differentiation of stress intensity.

Model parameterization

To simulate the maize production with EPIC, many different types of information are necessary to obtain realistic yields. Among the most important data required are information about the geographical location (latitude, longitude, elevation, etc.), soil data, management data, weather data and hydrological information (Williams et al., 2006). Table 1 shows the nature, source, scales and types of parameters required for applying the EPIC model in the study area. Each soil type is described through many parameters including hydrological soil group (derived from internal drainage characteristics) (Gaiser et al., 2010), number of soil horizon, albedo, previous years of cultivation, minimum and maximum depth of groundwater and soil organic matter pool (Liu, 2009). EPIC can accept up to 20 parameters for up to 10 soil layers. Specific information on soil layers such as number and depth of soil layer (m), bulk density (t/m³), sand content, silk content, carbon and organic content (%), cation exchange capacity (cmol/kg), saturated hydraulic conductivity (mm/h) (Liu, 2009; Tan and Shibasaki, 2003). In total six different soil types including 2 from each investigated locality together with their associated parameters were considered for the simulations (cf. Table 2). These parameters are combined with other abiotic parameters such as the mean annual weather conditions to compute a complex indicator of fertility (CIF) to discuss the simulation issues. The CIF (Lacatusu and Lacatusu, 2011) is defined as the difference between the sum of potentiating indicators (x) and the sum of the penalty indicators (y) and is expressed for agricultural soils by the Equation (5):

$$CIF = \sum_{i=1}^{12} x_i - \sum_{i=1}^{5} y_i \tag{5}$$

Where the potentiating indicators x_1 = annual average precipitations (mm), x_2 = annual average temperature (°C), x_3 = level of gleization, x_4 = level of pseudo-gleization, x_5 = textural class, clay content of <2µ (%), x_6 = edaphic volume (%), x_7 = bulk density (g cm^{-3}), x_8 = reaction pH$_{H2O}$, x_9 = humus content (%), x_{10} = total nitrogen content

Table 1. General model input data used in this study. Soil and land use data are from IMPETUS (Christoph et al., 2008) and INRAB (Institut National de la Recherche Agricole du Bénin; Igue, 2005), Climate data are from IMPETUS, IRD (Institut de Recherche pour le Développement), and DMN (Direction de la Météorologie Nationale). Management information are obtained from the MAEP (Ministère de l'Agriculture, de l'élevage et de la Pêche) and the CeRPA (Centre Régional de Promotion Agricole).

Data (data sources)	Scale	Parameter and types of investigation
Topography (DEM SRTM)	90 m resolution	Elevation and slopes.
Soil (SOTER INRAB and IMPETUS)	1 : 200,000	Saturated conductivity, organic carbon, bulk density, Texture, soil erodibility factor, soil available water content, pH, OrgN, etc.
Management (CountryStat, MAEP, CeRPA)	Commune level	Tillages, crop systems, conservation measures, fertlization, etc.
Weather (DMN, IRD, IMPETUS)	1 per site	Daily wind speed, precipitation, temperature, solar radiation, etc.

Table 2. Investigated site soil types and soil properties as used in the simulations. Only mean values of the topsoil (depth < 0.4 m) are displayed in this table.

Types and soil properties	Luvic arenosol (Bonou)	Eutric Vertisol (Bonou)	Eutric Vertisols (Ketou)	Ferric Acrisols (Ketou)	Haplic Lixisol (Nikki)	Eutric Gleysol (Nikki)
Topsoil depth (M) (total profile depth)	0.38 (1.2)	0.3 (0.6)	0.35 (0.7)	0.25 (1.6)	0.38 (1.2)	0.28 (0.7)
Soil porosity (M/M)	0.39	0.49	0.50	0.38	0.33	0.40
Field Capacity - soil water (M/M)	0.20	0.44	0.25	0.11	0.12	0.22
Saturated conductivity (MM/H)	5.01	1.92	22.00	37.69	22.46	4.59
Sand content (%)	61.50	19.65	51.35	82.90	81.70	58.47
Silt content (%)	22.25	23.70	30.85	14.70	9.85	22.43
Clay content (%)	16.25	56.65	17.80	2.40	8.45	19.10
Rock fraction (%)	2.60	5.30	7.65	5.30	15.00	2.60
pH_{H2O}	5.80	5.95	6.60	6.10	5.65	5.80
Cationic exchange capacity (CMOL/KG)	9.30	34.50	10.80	37.40	5.80	8.63
Organic P (G/T)	46.50	189.50	218.00	76.00	45.50	67.00
Organic N (G/T)	370.00	1515.00	1740.00	610.00	360.00	536.67
Organic C (%)	0.37	1.52	1.74	0.61	0.36	0.54

(%) or the amount of nitrogen index (NI), x_{11} = mobile phosphorus content (mg kg^{-1}), x_{12} = mobile potassium content (mg kg^{-1}); and the indicators for penalty y_1 = level of salinity, y_2 = level of alkalization, y_3 = level of carbonation, y_4 = level of pollution, y_5 = level of artifacts (%). Additionally to all the above-described general parameters, the model was provided with literature-based (sensitive/experimental-based/calibrated) validated model parameters under regional conditions for maize production in Benin, mainly from Gaiser et al. (2010b).

He pointed out that the physiological parameter set for maize in the EPIC database was only slightly changed to

Table 3. Scenario-based annual rainfall [mm] at decadal scale from 2000 to 2050. D = dry condition, W = wet condition. A dry year (resp. wet year) is considered as a year recording the smallest (resp. highest) amount of rainfall.

Variables	2000-2009 [Reference]	2010-2019	2020-2029	2030-2039	2040-2049
Nikki W+A1B	1302	1436	1270	1454	1370
Nikki D+A1B	1041	801	752	816	792
Nikki W+B1	1302	1309	1468	1314	1337
Nikki D+B1	1041	768	781	760	792
Bonou W+A1B	1258	1489	1340	1323	1309
Bonou D+A1B	862	783	803	773	715
Bonou W+B1	1258	1472	1485	1465	1353
Bonou D+B1	862	760	828	813	813
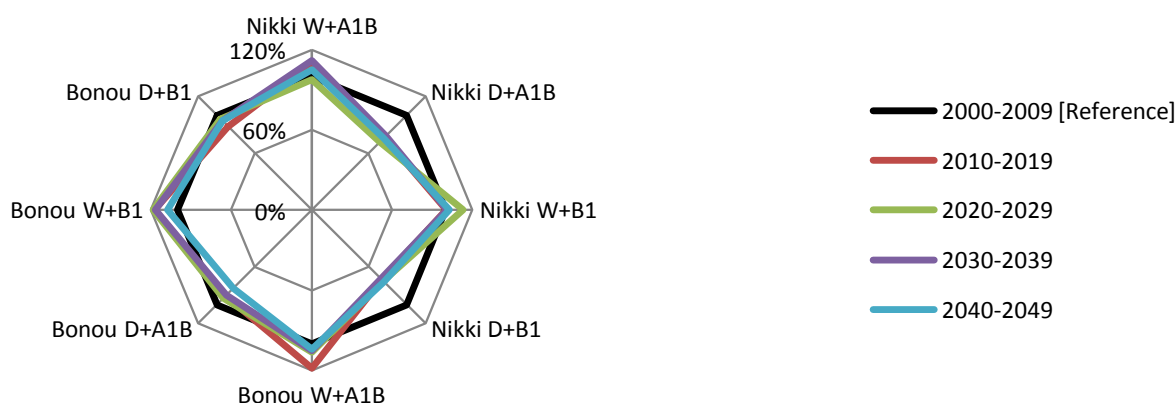
Figure 2. Relative changes in the scenario-based annual rainfall at decadal scale from 2000 to 2050. D = dry condition, W = wet condition. A dry year (resp. wet year) is considered as a year recording the smallest (resp. highest) annual amount of rainfall within a ten years period.

fit the conditions in Benin (Gaiser et al., 2010c). Nevertheless, it was found necessary to strike the values of the indicated most sensitive parameters by an uncertainty rate of ±20% to account for all potential uncertainties affecting the simulations. It is the case of 5 model parameters including the harvest index (HI = 0.35 [-]), the minimum harvest index (via WSYF = 0.01 [-]), the Aluminium tolerance index (ALT = 3 [-]), critical aeration factor [-] (CAF = 0.85) and previous years of cultivation (RTN = 50 years). Thus, a relatively large parameter matrix was created and used to evaluate maize yield at the three investigated locations, based on two different management scenarios associated with two sowing date scenarios and for a reference dry year (2001) and a reference wet year (2003) (cf. section 2.4 for detailed information on the different scenarios). A dry year is considered as a year recording the smallest amount of rainfall in a given decade, and a wet year recording the highest rainfall. The variability associated with the simulated yield was useful to estimate the possible production range at each location with the potential uncertainty. The results were finally used to validate the commune level observed yield, recorded by the Ministry of Agriculture and Livestock (MAEP) and published online (countrystat.org/ben).

The climate observation in Benin is based on a national rain-gauge network (under DMN authority, 'Direction Nationale de la Météorologie') counting roughly 100 measurement sites by 2005 (Diederich and Simmer, 2010). As already reported by Bossa et al. (2012) and documented in more detail by Speth et al. (2010), the

climate scenarios used were provided by Paeth et al. (2009) for the Africa continent between -15°S and 45°N latitude, using the regional climate model REMO driven by the IPCC SRES scenarios A1B and B1. REMO is a regional climate model that is nested in the global circulation model ECHAM5/MPI-OM (Paeth et al., 2008). Considering REMO initial runs, the rainfall amount and variability were systematically underestimated over West Africa with a shift in its pattern towards more weak events and fewer extremes (Paeth and Diederich, 2010). This has led to the application of MOS (Model Output Statistics) to adjust the rainfall data (monthly bias correction) using other near-surface parameters such as temperature, sea level pressure and wind components from the model. Since the regional-mean spatial patterns of daily rainfall events strongly differed from the observed a conversion of the MOS-corrected regional-mean data derived from REMO to local rainfall event patterns has been done. As reported by Gaiser et al. (2011), a weather generator (WEGE) was applied, producing virtual station data, matching the rainfall stations in Benin, which was finally adjusted to the statistical characteristics of observed daily precipitation at the rainfall stations by probability matching (Paeth and Diederich, 2010). Table 3 and Figure 2 show the scenario-based highest/lowest annual rainfall amounts at decadal scale from 2010 to 2050. It can be seen that rainfall amounts in the wet years will likely increase of up to 20% at all investigated locations, while decreasing in the dry years of up to 25% mainly occurs in the locality of Nikki.
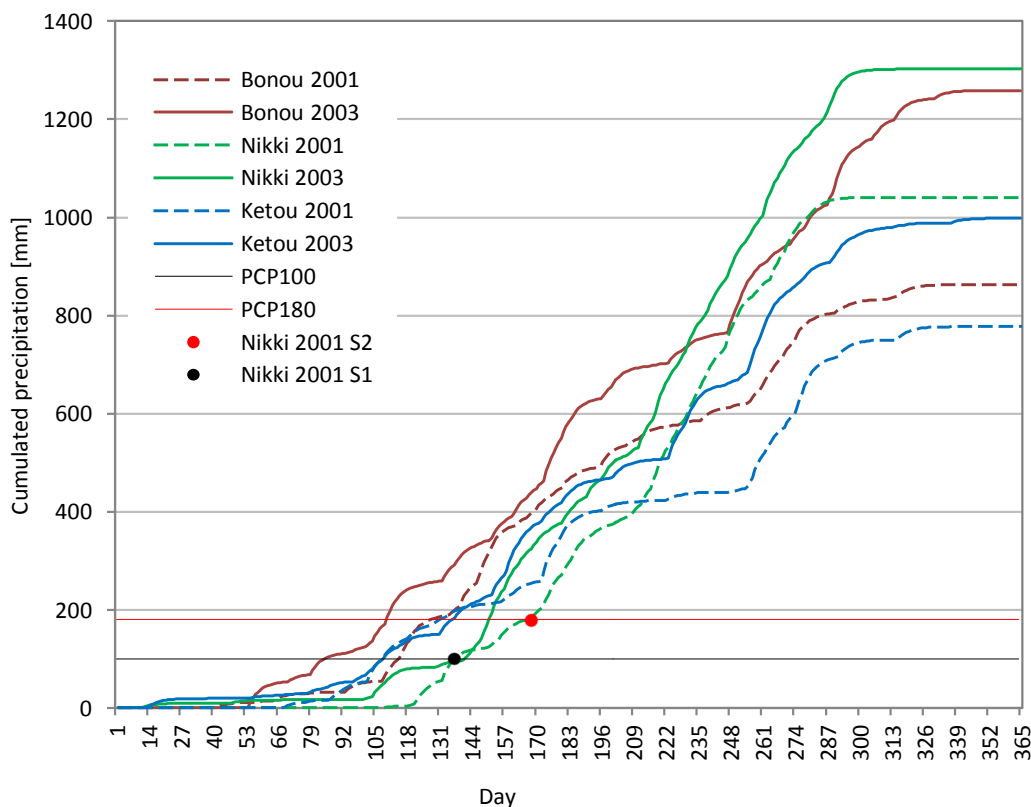
Figure 3. Rainfall distribution in 2001 and 2003 for the three communes Nikki, Ketou and Bonou. 100 and 180 mm cumulated rainfall are indicated by the black and red lines while the dots are examples indicating two different sowing dates in the dry year 2001 for the locality of Nikki.

Management scenarios

The most commonly used tools in the study area are the hoe and the machete (Bossa, 2012). Thus field preparation starts with cutting shrubs and bushes with machete, burning of trees and cleaning up with hoes depending on the season. Maize is grown with or without ridges and a spacing of 0.80 m is generally practiced for the ridges. From experience, the farmer often choose the best ridge orientation in order to significantly reduce losses of soil and nutrients and allow good water drainage of soils. Motor tractors are still rarely used by the farmers. Shifting cultivation is practiced (subsistence farming), consisting of cultivating the fields for a few years and leaving them for fallows in order to restore soil fertility. Agricultural inputs such as NPK and urea are currently at very low level but increasingly used for maize, cotton and rice. Mixed cropping practiced in the study area include yam-maize-okra, maize-cassava, maize-groundnut, maize-sorghum, or maize-cowpeas. Crop rotations are not very common in the cultural practices of farmers, since there is still enough potential cultivation spaces (due to relatively low population density in most parts of the Ouémé catchment). In this study crop associations and rotations are not considered.

EPIC requires a detailed description of management practices (Tan and Shibasaki, 2003). As common in Benin, the fertilizers NPK and Urea were specified in this study for maize production. Other variables were also specified: (1) the N and P element fractions of the total fertilizer applied to the soil surface, (2) the heat unit fraction for management operations, (3) tillage depth, (4) the mixing efficiency, etc. Heat unit may be defined as the accumulated

number of daily temperature degrees above a certain threshold base temperature (needed to reach plant maturity), which varies among crop species. The mixing efficiency of the tillage implement defines the fraction of the residue, nutrients, and bacteria pool in each soil layer that is redistributed through the depth of soil that is mixed by the implement (Bossa et al., 2012). The scenarios used in this study were based on the current management practices to give a realistic representation of the current situation. Two management scenarios essentially based on tillage and fertilizer use were considered. In both scenarios soil plowing is made with the hoe once at 25 cm depth following by two consecutive maintenance tillages to 10 cm depth. These are respectively assigned in the model with mixing efficiencies of 0.5 and 0.25. The first scenario describes the most widespread situation based on tillage schedule without fertilizer use, while the second scenario took in addition the use of fertilizer NPK and urea with annual rates of 80 kg ha^{-1} (NKP) and 40 kg ha^{-1} (urea) at all simulated locations. These amounts of fertilizer were taken from Kuhn et al. (2010a).

To set the cultivation period, two different scenarios of sowing dates (PCP100 and PCP180) were derived from the dates for cumulated amounts of mean annual rainfall amounts accounting for percentages of 7 to 15%, relying on the literature (Ilesanmi, 1972). An earlier sowing date was fixed to the day after the rainfall event that resulted in a cumulative rainfall of 100 mm, counting from the first day of the year (Figure 3), whereas the later sowing was set to the day after a threshold of 180 mm.

To take into account the effects of the climate conditions and to highlight the high rainfall variability within the region, the established management scenarios as well as the sowing date

Table 4. Abiotic factors and soil fertility status for the simulated sites.

Indicators		Soil type					
		Haplic Lixisol (Nikki)	Eutric Gleysol (Nikki)	Eutric Vertisols (Ketou)	Ferric Acrisols (Ketou)	Luvic arenosol (Bonou)	Eutric Vertisol (Bonou)
Potentiation factors	x_1= annual average precipitation (mm)	1	1	1	1	1	1
	x_2 = annual average temperature (°C)	1	1	1	1	1	1
	x_3 = level of gleization	0	2	5	0	5	5
	x_4 = level of pseudo-gleization	0	2	0	0	0	0
	x_5 = textural class, clay content of <2μm (%)	4	2	1	4	4	4
	x_6 = edaphic volume (%)	4	2	5	4	5	5
	x_7 = bulk density (g cm^{-3})	3	3	2	3	2	5
	x_8 = reaction pH$_{H2O}$	3	3	3	4	2	3
	x_9 = humus content (%)	2	2	2	2	2	1
	x_{10} = total nitrogen content (%)	4	5	5	5	5	5
	x_{11} = mobile phosphorus content (mg kg^{-1})	1	1	5	5	5	5
	x_{12} = mobile potassium content (mg kg^{-1})	4	4	3	3	3	3
Penality factors	y_1 = level of salinity	1	1	2	2	2	2
	y_2 = level of alkalization	0	0	1	1	1	1
	y_3 = level of carbonation	1	1	2	2	2	4
	y_4 = level of pollution	1	1	2	2	2	2
CIF		24	25	26	25	28	29
Fertility level		medium	medium	medium	medium	medium	medium

scenarios were combined with different soil conditions to simulate maize yield for the years with the highest/lowest annual rainfall amount observed for the period 2000 to 2009: (1) 2001 represents the reference dry year, and (2) 2003 the reference wet year. Figure 3 shows the rainfall distribution (cumulated amounts) for the reference years 2001 (dry) and 2003 (wet) for the three different locations investigated (Nikki, Ketou and Bonou).

RESULTS AND DISCUSSION

Variability of abiotic factors and fertility status for all investigated locations

As mentioned in model parameterization, soil parameters are combined with other abiotic factors such as the mean annual weather conditions to compute a complex indicator of fertility (CIF) (Lacatusu and Lacatusu, 2011), defined as the difference between the sum of potentiating indicators and the sum of the penalty indicators (Table 4). Fertility status was found medium at all investigated locations with slightly higher values for the South, mainly for the commune of Bonou showing a CIF of up to 28-29 against 24-25 for the North (Commune of Nikki). The fertility status in the commune of Ketou was found similar

to that of Nikki with a very small advantage (CIF of 25-26). This already suggests a decreasing gradient in yield production from the South to the North. To answer the research questions we split the modeling results into four parts: (1) Combined effects of management options – sowing date scenarios – variable abiotic factors on maize yield production; (2) Water and nitrogen stress under dry and wet conditions for the reference period (2000 to 2009); (3) Impacts of scenario-based rainfall conditions on maize yield production under sowing date sensitivity; and (4) Water and nitrogen stress under scenario-based dry and wet conditions at decadal scale from 2010 to 2050.

Combined effects of management options – sowing date scenarios – variable abiotic factors on maize production under different rainfall conditions for the reference period 2000 – 2009

Figure 4 shows the combined effects of management options – sowing date scenarios – variable abiotic factors on maize yield production with associated uncertainty ranges. Significant differences of up to 800 kg ha^{-1} a^{-1} of
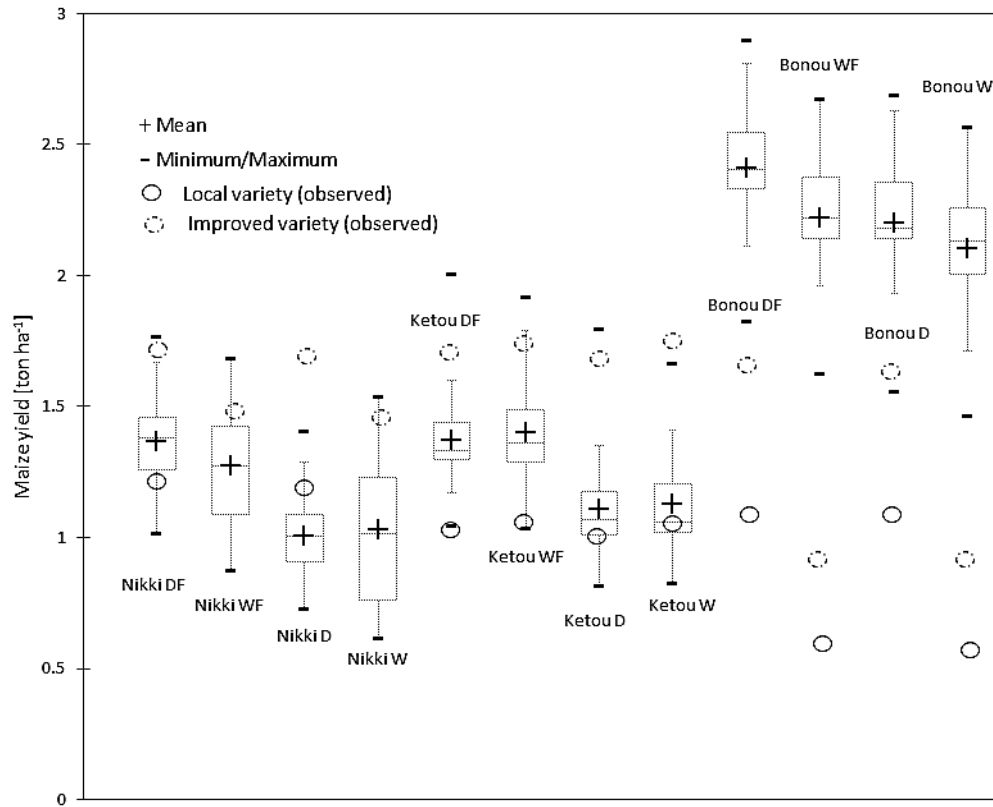
Figure 4. Box-wisker plots of the combined effects of management options – sowing date scenarios – variable abiotic factors on maize yield production under different rainfall conditions for all investigated communes (for the reference years 2001 and 2003). DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition. Local variety means a variety of maize grain traditionally cultivated in a given area. Improved variety means a maize grain variety that is experimentally selected to better fit to specific climate and soil conditions.

yield between the South (Bonou) and the North (Nikki) of the study area are indicated. Beyond catastrophic factors such as floods and pests the extreme yield productions are likely of about 500 to 1400 (±250) kg ha^{-1} a^{-1} in the North (Nikki) and 1100 to 2300 (±300) kg ha^{-1} a^{-1} in the South (Bonou). This is consistent with the soil fertility status, which is gradually higher in the South compared to the North. It is well known that the cultivation of maize is only possible by sufficient water availability (Zech and Hintermaier-Erhard, 2002). Given the fact that the simulations in Bonou included a Luvic Arenosol with also relatively high yield, it could be stated that moisture availability over the growing season as well as soil fertility were good in this region compared to the North. It can be seen from Table 4 that soil nitrogen and phosphorus indicators (x_{10} and x_{11}) are weak in the North (Nikki) compared to the South (Bonou) and this is critical for the most widespread soil type Haplic Lixisol (Table 4), which is already shown in many study as significantly affected by soil erosion (Bossa and Diekkrüger, 2012). This soil condition in the North does not allow optimal maize production. Similarly, it is not even the best soil condition

for maize production in the locality of Bonou, since Vertisol was found to be not suitable for maize cultivation in the tropics (Zech and Hintermaier-Erhard, 2002). As also shown in Figure 4, the observed yields for the local as well as the improved maize variety are within the simulated ranges for Nikki and Ketou, but are much lower than simulated for Bonou. This is in contrast to the fertility status in the locality of Bonou and is due to the fact that most of the agricultural lands in this commune are located in the Deltaic flooding zone of the Ouémé River. Two different negative scenarios are often observed: (1) the growing processes are significantly inhibited by high water saturation of the soils leading to reduction of the harvested yield; and (2) the growing processes are perfect until crop maturity, but finally destroyed before the harvest. The farmers usually avoid the second scenario by arbitrarily anticipating the harvesting activities. This completely escapes the control of the competent services of the Ministry of Agriculture (MAEP) and reports are only based on the normal harvesting time. MAEP usually provide statistics only for mean seasonal yields at commune level, hiding high disparities/spatial variations.

The EPIC model is unfortunately unable to simulate this inhibition of the growing processes, since it is a field scale model that is not dynamically linked to upland hydrology. Although the simulated results for Bonou could not be directly validated by the observations, it could be at least explained.

Contrary to the finding of Kuhn et al. (2010), no correlation was found between the annual rainfall precipitation and the simulated yield. This is rather consistent with the statement of Gruber et al. (2009), who emphasize that the annual precipitation is not meaningful for evaluating the influence of rainfall on maize production. This can also be explained by the fact that the minimum amount of annual rainfall for maize of 500 mm (Lafitte, 2000) is reached in all simulation years and locations. Even the total amount of rainfall during the growing period was not correlated with the yield. Higher rainfall amount in the dry year (2001) is found for Nikki compared to the wet year 2003. Additionally, the intra-seasonal rainfall patterns over the growing season (June – July – August) in Nikki is characterized by an additional monthly rainfall amount of roughly 40 mm compared to the South (an example is shown in Figure 1). During the growing period Nikki recorded in mean about 270 mm more rainfall than Bonou, nevertheless the yield is higher in Bonou (calculations were based on the reference years 2001 and 2003). The arising question is whether this particular rainfall pattern (good water availability within the growing period) is negatively affecting the maize yield production at this location (Nikki). But this situation at least explained the higher variability in the yield obtained in Nikki compared to the others locations (Ketou and Bonou) (as shown in Figure 4). For analyzing crop production's dependence on available water, the investigation of the agronomic water availability is useful. It is an outcome of the meteorological water availability but also considers evapotranspiration, the groundwater table, as well as the water demand of plants (Dikau and Weichselgartner, 2005). Although the calculation is not simple, the EPIC model as used in this work was parameterized to account for that, even the modeled yield at this location (Nikki) are well validated by the observations as discussed in the previous paragraph and presented in Figure 4. From analyzing the management scenarios it can be concluded that even though the fertilizer amount used in the simulations are relatively low they resulted in higher yields in all communes (Figure 4). This is consistent with Kormawa et al. (2003). The amount of fertilizer was set equal for the three communes even if in the South the currently used amount is almost zero in many small farming systems. The use of fertilizer could help overcoming the problem of increasing land scarcity due to population growth and be an incentive for intensification instead of shifting agriculture (Kuhn et al., 2010a). "Higher productivity on existing farmland will reduce cultivation extension into forest or savannahs" (Angelsen and Kaimowitz, 2001). It could be assumed that as long as there is still new land available and fertilizer remains expensive, farmer would never invest in fertilizer use. This is already expressed with the theory of Boserup (1965).

Regardless the use of fertilizer the planting date is one of the most important factors influencing the maize production. As previously mentioned the sowing date determines the moisture availability through the growing season as well as the schedule of management practices such as tillage and fertilizer use. The sowing date scenarios contributed to the variability in the yield as displayed in Figure 4. This contribution can be better observed in Figure 5. The highest sensitivity is pointed out for Nikki. Higher yield production was in general associated with earlier sowing date and this was significantly pronounced in the wet years. It can be clearly seen from Figure 5 that sowing date influence maize yield by ± 500 kg ha^{-1} in Nikki, but only ± 100 kg ha^{-1} in Ketou and Bonou.

Water and nitrogen stress under dry and wet conditions for the reference period (2000 to 2009)

As indicated before, changes in plant growth limiting factors such as water stress and nitrogen stress were conjointly analyzed under different management options to account for not only the effects of rainfall variability, but also soil fertility status and pressure status on the land resources. The increasing gradient in the yield production from the South to the North can be once more explained with Figure 6 presenting water and nitrogen stress days and fraction of the total limiting factors.

It appears that nitrogen stress is clearly significantly higher than water stress by more than 50% over all regions. It can be assumed that the medium soil fertility pointed out all over the region is the main explanation. Specifically, high nitrogen stress is observed for Nikki and may be associated with the most widespread soil type Lixisols in the North. This is consistent with Table 4, showing a weak nitrogen indicator (xi_{10}) for Nikki compared to Ketou and Bonou. As mentioned before, there are studies (Bossa and Diekkrüger, 2012) that have clearly shown a strong link of soil erosion with this soil type. Even the use of fertilizer NPK and urea only reduce the stress by about 5% (Figure 6). It should be noticed that although the required total annual rainfall amount is met all over the study region (Lafitte, 2000), water stress was shown as the dominant limiting factor in the South, due to better soil fertility status (commune of Bonou) and the intra-seasonal rainfall pattern characterized by a relatively low rainfall amount over the growing period. This is not the case of the North (commune of Nikki) characterized by sever nitrogen stress, due to high sensitivity of soil resources to constant pressures leading to poorer soil fertility status with time. This is also due to intra-seasonal rainfall patterns characterized by an
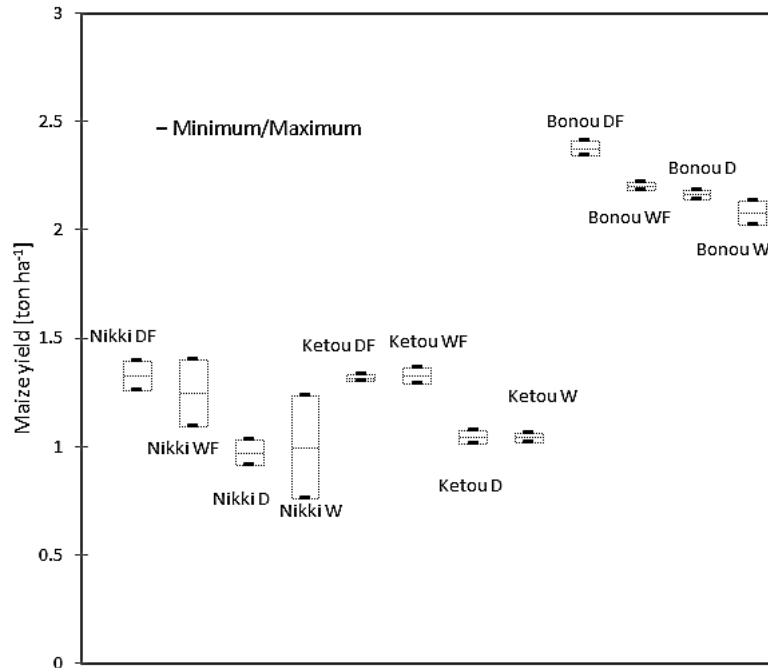
Figure 5. Sensitivity of the maize yield to sowing date in the three communes under different management scenarios (for the reference years 2001 and 2003). DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition.

additional monthly rainfall amount of roughly 40 mm compared to the South. It becomes clear that the heterogeneity in natural conditions (variability in the abiotic factors) influenced the yield all over the investigated communes and the use of fertilizer is more efficient in the North, due to higher nitrogen stress.

Impacts of scenario-based rainfall variability on maize yield production under sowing date sensitivity

The impacts of climate change on maize production until 2050 are presented in the Tables 5, 6 and 7 as well as Figure 7. Due to the contrasting differences up to here shown between the North and the South, only Bonou and Nikki were considered for the analysis. The figures show relative changes (in reference to the period 2000 to 2009) in the maize yield under rainfall variability (dry and wet years at decadal scale, based on the IPCC scenario-based A1B and B1) and different management options as well as different sowing date scenarios. An overall decreasing trend reaching -50% is indicated for maize production by 2050 due to climate changes. Two majors issues are pointed out in Nikki under the climate scenario A1B (Figure 7a): (1) combined effects of dry conditions in the scenario A1B and the early sowing date scenario PCP100 have resulted in a reduction of yield close to -50%, while (2) the combined effects of dry conditions in

the same climate scenario A1B, fertilizer use and the late sowing date scenario PCP180 have resulted in a stable production level compared to the reference period 2000 to 2009. These are very contrasting results since it was clear on one hand that fertilizer has a positive effect on the production, and on the other hand that the early sowing date scenario PCP100 has also a positive effect on the production computed for the observed period 2000 to 2009. This is simply indicating an inversion of the situation for the future decades, where a rather late sowing date combined with fertilizer use should be the potential alternative to a stable production level. For climate scenario B1, two majors issues are pointed out in Nikki (Figure 7b): (1) combined effects of wet conditions in the scenario B1 and the early sowing date scenario PCP100 have resulted in a reduction of less than -30% and close to -50%, while (2) the combined effects of wet conditions in the same scenario B1, fertilizer use and the late sowing date scenario PCP180 have resulted in a stable production level (even more) as computed for the reference period 2000 to 2009. These are also very contrasting results that may have the same understanding as explained above in the case of the scenario A1B for the same location Nikki. It could be concluded from these analyses that with respect to the climate scenarios used (from 2010 to 2050), extremely low maize yields may be avoided if optimal sowing dates are chosen after an accumulated rainfall significantly
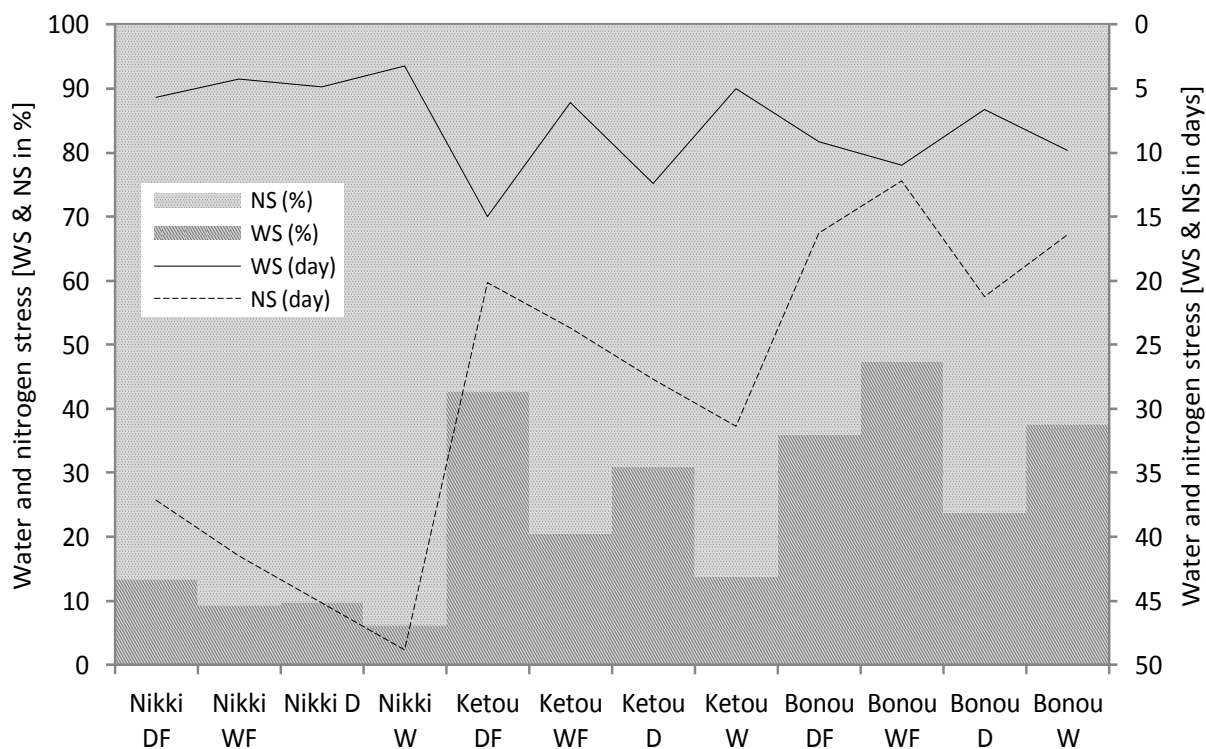
Figure 6. Water and nitrogen stress as percentages of total stress occurrences for all investigated communes under different management scenarios and different rainfall conditions (for the reference years 2001 and 2003). DF = dry condition + fertilizer.

more than 100 mm, regardless dry or wet conditions.

In Bonou, only the late sowing date scenario PCP180 was considered for investigating climate changes impacts on the yield production, since the sowing date impacts were previously found very weak. Generally, maize yield sensitivity to climate changes at this location is higher than found in Nikki. It could be seen that the yield production is almost insensitive to the type of climate scenarios (A1B and B1) as well as the fertilizer use option. Only dry and wet conditions have shown to impact the production either negatively or positively. This suggests that, with respect to the climate change scenarios, a stable or an increase yield compared to the period 2000 to 2009 can be reached in Bonou with increased moisture availability.

Water and nitrogen stress under scenario-based dry and wet conditions at decadal scale from 2010 -2050

Figure 8 presents the trend in the water and nitrogen stress for Bonou and Nikki under rainfall variability (climate change scenarios A1B and B1), sowing date scenarios (corresponding to cumulated rainfall more than 100 and 180 mm) and management scenarios (fertilizer use). This figure revealed an overall increase in water stress by 2050. This is critical for Bonou where more than

50% increase is shown, compared to Nikki (30%). Nitrogen stress in the North (resp. water stress in the South) is expected to reach 95 % (resp. 100%) of the total stress factors depending on the management options by 2050. High water stress is generally associated with the climate scenario A1B compared to the scenario B1. Moreover, higher water stress is associated with earlier sowing dates, while higher nitrogen stress is associated with the late sowing date (with respect to the climate scenarios over the period 2010 to 2050).

It could be seen that these results are consistent with the previous finding indicating that future sowing date should be shifted significantly towards a cumulated rainfall of 180 mm to avoid extremely low yield production, while reducing significantly water stress. It should be highlighted that this will offer a possibility to make efficient use of fertilizer. From field experiences, it is often observed that despite the use of high fertilizer amount the harvested yields are very low. These results clearly explained why. It is due to inadequate setting up (beginning) of the growing season. Under rainfall conditions (rainfed agriculture), inadequate beginning of the growing season may result in high water stress as dominant limiting factor, and this could not be unfortunately solved by putting high amount of fertilizer. Fertilizer can only lead to higher crop production when

Table 5. Simulated maize yields for Nikki (in tons ha^{-1}) under rainfall variability (climate change scenario A1B), sowing date scenarios (corresponding to cumulated rainfall of 100 mm and 180 mm) and management scenarios (fertilizer use). DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition.

Nikki [A1B]	2000-2009 [Reference]	2010-2019	2020-2029	2030-2039	2040-2049
W+PCP180+A1B	1.39	1.07	0.75	1.05	1.34
D+PCP100+A1B	1.40	1.18	1.25	1.10	1.06
W+F+PCP100+A1B	1.03	0.63	0.52	0.71	0.94
W+F+PCP180+A1B	1.23	0.76	0.77	0.67	0.72
W+F+PCP180+A1B	1.26	1.15	0.97	0.89	1.12
D+PCP100+A1B	1.09	1.11	1.08	1.13	1.04
D+F+PCP100+A1B	0.91	0.66	0.54	0.56	0.68
D+PCP180+A1B	0.76	0.65	0.64	0.63	0.62

Table 6. Simulated maize yields for Nikki (in ton ha^{-1}) under rainfall variability (climate change scenario B1), sowing date scenarios (corresponding to cumulated rainfall of 100 mm and 180 mm) and management scenarios (fertilizer use). DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition.

Nikki [B1]	2000-2009 [Reference]	2010-2019	2020-2029	2030-2039	2040-2049
D+PCP180+B1	1.39	1.39	1.12	0.90	0.97
D+PCP100+B1	1.40	1.31	1.22	1.17	1.14
D+F+PCP180+B1	1.03	0.91	0.69	0.63	0.63
D+F+PCP100+B1	1.23	0.88	0.68	0.81	0.67
W+PCP100+B1	1.26	1.21	1.21	0.99	1.08
W+F+PCP180+B1	1.09	1.08	1.04	1.00	1.22
W+PCP180+B1	0.91	0.69	0.75	0.61	0.67
W+F+PCP100+B1	0.76	0.67	0.60	0.61	0.63

Table 7. Simulated maize yields for Bonou (in ton ha^{-1}) under rainfall variability (climate change scenarios A1B and B1), sowing date corresponding to cumulated rainfall 180 mm and management scenarios (fertilizer use). DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition.

Bonou [A1B & B1]	2000-2009 [Reference]	2010-2019	2020-2029	2030-2039	2040-2049
D+PCP180+B1	2.34	1.22	1.46	1.41	1.30
D+PCP180+A1B	2.18	1.77	1.72	1.29	1.29
D+F+PCP180+B1	2.14	1.20	1.39	1.30	1.23
D+F+PCP180+A1B	2.02	1.64	1.55	1.29	1.22
W+PCP180+A1B	2.34	1.61	1.57	1.33	1.48
W+F+PCP180+B1	2.18	2.01	1.59	1.11	1.70
W+PCP180+B1	2.14	1.53	1.46	1.25	1.41
W+F+PCP180+A1B	2.02	1.67	1.50	1.07	1.53

soil fertility constrains the crop growth. Considering the fact that land resources are becoming scarce with significant reductions of shifting agriculture or fallow systems, efficient use of fertilizer (regardless the types) will be the potential alternatives for farmers in Benin to secure the food production in the future.

One can conclude by stating that with respect to the climate scenarios, possibilities are clearly offered to Benin to successfully deal with food security in the future (by 2050) by increasing or at least keeping stable the

rainfed maize production. As a relatively low fertilizer amounts are currently used in the country (compared to rainfall of 100 mm towards sowing dates corresponding to 180 mm (cumulated rainfall) can be combined with increasing rate of fertilizer to enhance maize production.

Conclusion

On the global scale, climate change will influence the
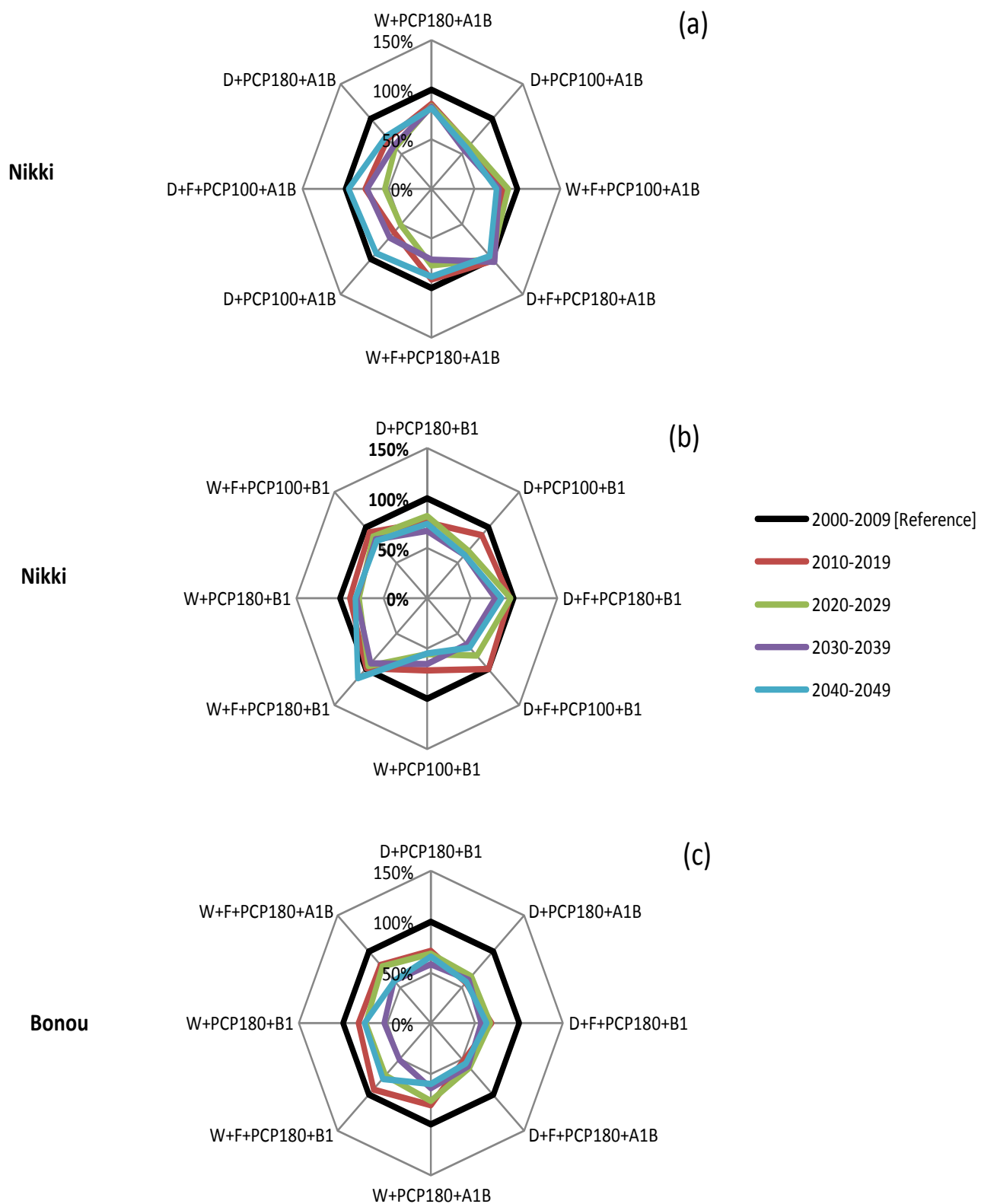
Figure 7. Simulated relative changes in maize yields for Bonou (referring to the period 2000 to 2009) under rainfall variability, sowing date corresponding to cumulated rainfall of 180 mm and management scenarios (fertilizer use). (a): climate change scenario A1B, (b): climate change scenario B1, (c): climate change scenario A1B and B1. DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition.
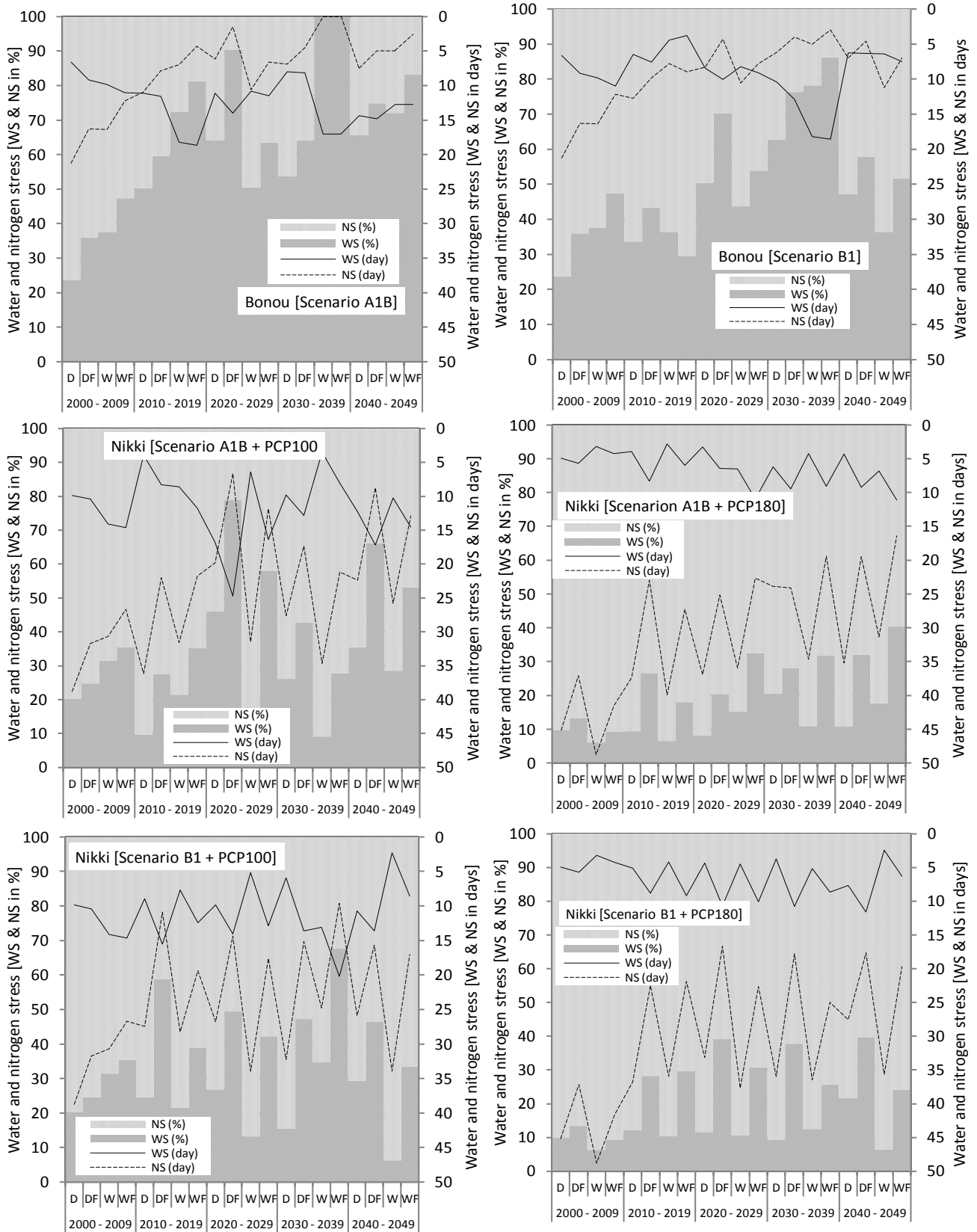
Figure 8. Water and nitrogen stress for Bonou and Nikki under rainfall variability (climate change scenarios A1B and B1), sowing date scenarios (corresponding to cumulated rainfall of 100 and 180 mm) and management scenarios (fertilizer use). DF = dry condition + fertilizer, WF = wet condition + fertilizer, D = dry condition, W = wet condition.

food situation (FAO, 2008; Kang et al., 2009). The high dependency of agricultural production on climate conditions has a negative effect on food production and increasing food prices lead to a more difficult access to other West African countries or Western countries), shifting the sowing dates corresponding to a cumulated food. West African countries including Benin are highly dependent on rainfed agriculture. Up to date a stable yield production at a low level is mainly the results of shifting agriculture based on fallow systems and inefficient fertilizer uses (Igué, 2000). Facing with increasing food demands as well as with increasing dry spells during the rainy season (Christoph et al., 2008), relevant issues are specific adaptation and resilience measures under different sub-regional conditions. This study successfully analyzed effects of different soil conditions, management options, different sowing dates and climate change conditions on maize production at different sub-regional scales in Benin. Occurrences of plant growth limiting factors such as water and nitrogen stress were successfully linked to spatial/intra-seasonal rainfall pattern and pressures on land resources.

The EPIC model (Williams et al., 1989) has been successfully applied at three different locations (from the South to the North of the Ouémé catchment, 50,000 km², Benin) with contrasting rainfall patterns, different edaphic conditions and fertility status. Contrary to the finding of Kuhn et al. (2010), no correlation was found between the annual rainfall precipitation and the simulated yield. This was found rather consistent with Gruber et al. (2009) as well as Lafitte (2000) pointing out a minimum annual rainfall of 500 mm for maize production, which is always met in the simulated years and locations considered in the study. Because the growing period in the North usually records in average 200 mm of rainfall more than the South, nitrogen stress is currently the limiting factor in the North in opposite to the South where water stress was revealed as the dominant limiting factor. This was in agreement with the significantly higher yields simulated for the South as response to favorable fertility conditions.

The impact of climate change on maize production under IPCC scenarios A1B and B1 specified for Benin (2010 to 2050) does not result in a dramatic or non-manageable situation. Higher yields were associated with the late sowing dates in opposite to the reference period (2000 to 2009) where higher yield were associated with the early sowing dates. An overall increase in the water stress of up to 50% was shown in all considered sub-regions. Higher water stress was associated with earlier sowing date, while higher nitrogen stress was associated with the late sowing date. Although a decrease of maize production of up to 50% may be caused by climate change, this study has indicated potential management options to keep stable or even increase the maize production. Therefore, shifting towards late sowing dates corresponding to a cumulated rainfall of 180 mm may reduce water stress and make efficient fertilizer use. It

has to be mentioned that the impact of sowing dates on the maize yield were within the same magnitudes of that of climate changes. One can conclude that the current study has demonstrated the importance of having a differentiated regard on the various factors affecting maize production in Benin to specific adaptations and management strategies at regional scale.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

REFERENCES

Agbossou E, Toukon C, Akponikpe PBI, Afouda A (2012). Climate variability and implications fpr maize production in Benin: A stochastic rainfall analysis. Afr. Crop Sci. J. 20:493-503.

Angelsen A, Kaimowitz D (Hrsg.) (2001). Agricultural Technologies and Tropical Deforestation. CABI Publishing and Center for International Forestry Research (CIFOR) Wallingford and New York.

Ati OF, Stigter CJ, Oladipo EO (2002). A comparison of methods to determine the onset of the growing season in Northern Nigeria. Int. J. Climatol. 22:731-742.

Baldwin BS, Cossar RD (2009). Castor yield in response to planting date at four locations in the South-central United States. Industrial Crops Prod. 29(2-3):316-319.

Boserup E (1965). The Conditions of Agricultural Growth the Economics of Agrarian Change Under Population Pressure. (Earthscan Publications Ltd.) London.

Bossa AY (2012). Multi-scale modelling of sediments and nutrient flow dynamics in the Ouémé catchment (Benin) – towards an assessment of global change effects on soil degradation and water quality. Ph.D. thesis. University of Bonn. http://hss.ulb.uni-bonn.de/2012/2983/2983.htm.

Bossa AY, Diekkrüger B (2012). Estimating scale effects of catchment properties on modeling soil and water degradation. In: R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.). Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, International Environmental Modelling and Software Society (iEMSs), Sixth Biennial Meeting, Leipzig, Germany. ISBN: 978-88-9035-742-8. pp. 2974-2981.
http://www.iemss.org/sites/iemss2012//proceedings/I4_0572_Bossa_Diekkrueger.pdf [01.07.2013].

Bossa AY, Diekkrüger B, Giertz S, Steup G, Sintondji LO, Agbossou EK, Hiepe C (2012b). Modeling the effects of crop patterns and management scenarios on N and P loads to surface water and groundwater in a semi-humid catchment (West Africa). Agric. Water Manag. 115:20-37.

Bossa AY, Diekkrüger B, Igué AM, Gaiser T (2012a). Analyzing the effects of different soil databases on modeling of hydrological processes and sediment yield in Benin (West Africa). Geoderma. pp. 61-74, 173–174.

Busche H, Hiepe C, Diekkrüger B (2005). Modeling the Effects and Land Use and Climate Change on Hydrology and Soil Erosion in a Sub-humid African Catchment. 3rd International SWAT Conference Proceedings, Zurich. http://www.brc.tamus.edu/swat/3rdswatconf/Bookofabstracts - 3rdswatconf1.pdf (consulted on 10.03.2011).

Christoph M, Fink AH, Paeth H, Born K, Kerschgens M, Piecha K (2008). IMPETUS: Implementing Help in the Upper Ouémé basin. In: Water SA 34(34):481-489.

Diederich M, Simmer C (2008). Observations of Past and Present Rainfall in Benin. In: IMPETUS Atlas Benin. Research Results 2000 – 2007 – 3rd Edition. Department of Geography of Bonn, Germany: 19–20. http://www.impetus.uni-koeln.de/en/impetus-atlas/.

Diederich M, Simmer C (2010). Weather and climate monitoring in Benin. In: Speth, P., Christoph, M., Diekkrüger, B., (Eds.) Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa. Springer Heidelberg Germany pp. 114-121.

Diepen CA, van der Wall T (1996). Crop growth monitoring and yield forecasting at regional and national scale. In: J.F. Dallemend, P. Vossen (Eds.), Proc. Workshop for Central and Eastern Europe on Agrometeorological Models: Theory and Applications, the MARS Project Ispra, Italy, November 21–25, 1994. Eur. Com. Luxembourg pp. 143–157.

Dikau R, Weichselgartner J (2005). Der unruhige Planet. Der Mensch und die Naturgewalten. (Primus Verlag) Darmstadt.

Egli DB, Cornelius PL (2009). A regional analysis of the response of soybean yield to planting date. Agronomy J.101 (2):330–335.

FAO (2008). Climate change and food security: a framework document. Food and Agriculture Organization of the United Nations, Rome, P. 107. http://www.fao.org/forestry/15538-079b31d45081fe9c3dbc6ff34de4807e4.pdf [24.06.2013].

Faure P, Volkoff B (1998). Some factors affecting regional differentiation of the soils in the Republic of Benin (West Africa). Catena 32:281-306.

Fink AH, Christoph M, Born K, Brücher T, Piecha K, Pohls S, Schulz O, Ermert V (2010a). Climate. In: Speth P, Christoph M, Diekkrüger B, Bollig M (Hrsg.): Impacts of global change on the hydrological cycle in West and Northwest Africa. Springer Heidelberg Germany pp. 54-59.

Gaiser T, De Barros I, Sereke F, Lange FM (2010b). Validation and reliability of the EPIC model to simulate maize production in small-holder farming systems in tropical sub-humid West Africa and semi-arid Brazil. Agric. Ecosyst. Environ. 135:318-327.

Gaiser T, Goldbach H, Giertz S, Hiepe C, Klose A (2010a). Soils. In: Speth, P., Christoph, M., Diekkrüger, B., (Eds.) Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa. Springer Heidelberg Germany pp. 46-52.

Gaiser T, Judex M, Igué AM, Paeth H, Hiepe C (2011). Future productivity of fallow systems in Sub-Saharan Africa: Is the effect of demographic pressure and fallow reduction more significant than climate change?. Agric. For. Meteorol. 151:1120-1130

GDB, WFP, FAO (2009). République du Benin. Analyse Globale de la Vulnérabilité, de la Sécurité Alimentaire et de la Nutrition (AGVSAN). (données de novembre et décembre 2008). Gouvernement du Bénin, Institut National de la Statistique et de l'Analyse Economique (Bénin), Programme Alimentaire Mondial, Fonds de Nations Unies pour l'Enfance et Organisation des Nations Unies pour l'alimentation et l'agriculture. http://documents.wfp.org/stellent/groups/public/documents/ena/wfp203247.pdf) [14.02.2013].

Gruber I, Kloos J, Schopp M (2009). Seasonal water demand in Benin´s agriculture. J. Environ. Manage. 90:196-205.

Heldmann M, Doevenspeck M (2008). Demography: Spatial Disparities and Hight Growth Rates. In: IMPETUS Atlas Benin. Research Results 200-2007 - 3rd edition. Department of Geography, University of Bonn, Germany: 103 - 104. http://www.impetus.uni-koeln.de/en/impetus-atlas/

Hiepe C (2008). Soil degradation by water erosion in a sub-humid West-African catchment, a modelling approach considering land use and climate change in Benin. Doctoral Thesis University of Bonn, Germany. Available: http://hss.ulb.uni-bonn.de/2008/1628/1628.htm[05.04.2011].

Igué AM (2005). Soil information system for the Oueme basin. http://www.rivertwin.de/ assets/publications/D15_ SLISYS_Oueme basin2.pdf [05.08.2009].

Ilesanmi OO (1972). An empirical formulation of the onset, advance and retreat of rainfall in Nigeria. In: J. Trop. Geogr. 34:17-24.

IPCC (2001). Climate Change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Junge B (2004). Die Böden des oberen Ouémé-Einzugsgebietes in Benin/Westafrika - Pedologie, Klassifizierung, Nutzung und Degradierung. Dissertation. Institut für Bodenkunde. Bonn, Universität Bonn. http://hss.ulb.uni-bonn.de/2004/0401/0401-dt.htm

Kang Y, Khan S, Ma X (2009). Climate Change impacts on crop yield, crop water poductivity and food security - A review. Nat. Sci. 19:1665-1674.

Kniveton DR, Layberry R, Williams CJR, Peck M (2009). Trends in the start of the wet season over Africa. Int. J. Climatol. 29(9):1216-1225.

Kormawa P, Munyemana A, Soule B (2003). Fertilizer market reforms and factors influencing fertilizer use by small – scale farmers in Benin. Agriculture, Ecosyst. Environ. 100:129-136.

Kuhn A, Gruber I (2010). Climate and socio-economic impacts on Benin´s agriculture. In: Speth P, Christoph M, Diekkrüger B, Bollig M (Hrsg.). Impacts of global change on the hydrological cycle in West and Northwest Africa. Springer, Heidelberg, Germany, pp. 316-328.

Kuhn A, Gaiser T, Gandonou E (2010a). Simulating the effects of tax exemption on fertiliser use in Benin by linking biophysical and economic models. Agric. Syst. 103:509-520.

Kuhn A, Gruber I, Heidecke C (2010b). Economy and Infrastucture. In: Speth P, Christoph M, Diekkrüger B, Bollig M (Hrsg.). Impacts of global change on the hydrological cycle in West and Northwest Africa. Springer, Heidelberg, Germany, pp. 82-87.

Kuhn A, Gruber I, Heidecke C (2010c). Economy and Infrastucture. In: Speth P, Christoph M, Diekkrüger B, Bollig M (Hrsg.). Impacts of global change on the hydrological cycle in West and Northwest Africa, 82-87. Springer, Heidelberg, Germany.

Lacatusu R, Lacatusu AR (2011). Complex indicator for assessing soil fertility. Res. J. Agric. Sci. 43(3):95-101.

Lafitte HR (2000). Abiotic stresses affecting maize. In: Paliwal RL, Granados G, Lafitte HR, Violic D (Hrsg.): Tropical Maize. Imporvment and production. FAO Plant Production and Protection Series. 28:93-103.

Laux P, Kunstmann H, Bardossy A (2008). Predicting the regional onset of the rainy season in West Africa. International Journal of Climatology 28(3):329-342.

Laux P, Jäckel G, Tingem RM, Kunstmann H (2010). Impact of climate change on agricultural productivity under rainfed conditions in Cameroon – A method to improve attainable crop yields by planting date adaptations. Agricultural and Forest Meteorology 150:1258-1271.

Liu J (2009). A GIS – based tool for modelling large – scale crop water relations. Environmental Modelling & Software 24:411-422.

Mandal N, Nag K, Ghosh M (2005). Planting date effects on phenological development, yield, and quality of hybrid rice. Trop. Agric. 82(1–2):34–39.

Monteith JL (1977). Climate and the efficiency of crop production in Britain. Philosophical Transactions of the Royal Society B 281:277-294.

Ndomba M (2010). Development of Rainfall Curves for Crops Planting Dates: A Case Study of Pangani River Basin in Tanzania. Nile Basin Water Sci. Eng. J. 3:13-27.

Odekunle TO (2006). Determining rainy season onset and retreat over Nigeria from precipitation amount and number of rainy days, Theor. Appl. Climatol. 83:193-201.

Odekunle TO, Balogun EE, Ogunkoya OO (2005). On the prediction of rainfall onset and retreat dates in Nigeria. Theor. Appl. Climatol. 81:101-112.

Olaniran OJ (1983). The onset of the rains and the start of the growing season in Nigeria, Nig. Geogr. J. 26 (1-2):81-88.

Paeth H, Born K, Heuer KO (2008). Human Activity and Future Climate Change. In: IMPETUS Atlas Benin. Research Results 200-2007 - 3rd edition. Department of Geography, University of Bonn, Germany: 13–

14. http://www.impetus.uni-koeln.de/en/impetus-atlas/

Paeth H, Diederich M (2010). Postprocessing of simulated precipitation for impact research in West Africa. Part II: A weather generator for daily data. Climate Dynamics, 36(7):1337-1348.

Sintondji L (2005). Modeling the rainfall-runoff process in the Upper Ouémé catchment (Térou in Benin Republic) in a context of global change: extrapolation from the local to the regional scale. PhD Thesis in Hydrology and Environmental Management of the Mathematics and the Natural Sciences Faculty of the University of Bonn. Shaker Verlag GmbH., Aachen Germany.

Speth P, Christoph M, Diekkrüger B (2010). Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa. Springer, Heidelberg, Germany.

Stern RD, Dennett MD, Garbutt DJ (1981). The start of the rains in West Africa. J. Climatol. 1:59-68.

Tan G, Shibasaki R (2003). Global estimation of crop productivity and the impact of global warming by GIS and EPIC integration. Ecol. Model. 168:357-370.

van den Akker E (2000). Makroökonomische Bewertung der Auswirkungen von technischen und institutionellen Innovationen in der Landwirtschaft in Benin. Dissertation. Universität Hohenheim. Stuttgart.

Waongo M, Laux P, Traoré SB (2014). A Crop Model and Fuzzy Rule Based Approach for Optimizing Maize Planting Dates in Burkina Faso, West Africa. J. Appl. Meteorol. Climatol. 53:598-613. doi: 10.1175/JAMC-D-13-0116.1.

Wezel A, Böcker R (2000). Vegetation of Benin. In: Graef, F.; Lawrence, P. & M. von Oppen (Hrsg.): Adapted Farming in West Africa: Issues, Potentials and Perspectives - Final Report (1986-1999) of the Special Research Programme 308 "Adapted Farming in West Africa". Verlag Ulrich E. Grauer (University of Hohenheim) Stuttgart: pp. 219-225.

Williams J (1995). The EPIC model. In: Singh V (Hrsg.): Computer Models of Watershed Hydrology Highlands Ranch, USA: pp. 909-1000.

Williams JR, Jones CA, Kiniry JR, Spanel DA (1989). "The EPIC Crop Growth Model." Trans. ASAE 32(2):497-511.

Williams J, Wang E, Meinadus A, Harman WL, Siemers M, Atwood JD (2006). EPIC User Manu Guide v.0509. http://epicapex.brc.tamus.edu/media/23015/epic0509usermanualupdated.pdf [03.01.2013].

Zech W, Hintermaier – Erhard G (2002). Böden der Welt. (Spektrum) Heidelberg.

Full Length Research Paper

Technical efficiency of fenugreek production in the semi arid region of Rajasthan, India: A stochastic frontier approach

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This paper examines the technical efficiency of fenugreek production in Rajasthan and also identifies key variables affecting technical efficiency using primary data collected from 120 randomly selected fenugreek cultivating farmers by applying a stochastic frontier analysis (SFA). The results obtained in an empirical model indicated that mean technical efficiency of all categories of farmers was 70%. This suggests that still there is scope for increasing the output by 30% with the same level of input uses. Small farmers were found to be more efficient in terms of judicious and timely application of irrigation and fertilizers as well as reaping more yields. Around 50% of the farmers attained a technical efficiency more than 80% because of employing the uniform cultivation practices. The results of the technical inefficiency effects model suggest that age, education and contact with extension agencies positively influenced technical efficiency of fenugreek cultivation.

Key words: Cobb-Douglas production function, fenugreek cultivation, semi-arid region, stochastic frontier analysis (SFA), technical efficiency.

INTRODUCTION

Seed spices constitute an important group of agricultural commodities and play a significant role in our national economy. Historically, India has always been recognized as a land of spices. Major seed spices are coriander, cumin, fennel and fenugreek (NRCSS, 2007). Among these spices, fenugreek *(Trigonella foenum graecum)* commonly known as *methi,* in Hindi has been used as a culinary spice, a flavoring agent and as a medicinal plant for centuries (Mathur and Choudhry, 2009). It is cultivated abundantly in India and the country contributes around 70 to 80% of the worlds' export share of fenugreek (Pruthi, 2001; Agarwal et al., 2001). Presently, Rajasthan,

Gujarat, Uttarakhand and Uttar Pradesh are the leading states for fenugreek production. Rajasthan accounts for around 87% of the total area and 75% of the total production of fenugreek in the country (Indiastat, 2012). In spite of significant progress achieved during the last two decades in seed spices production in India, the average productivity of these crops is still low as compared to the best yields at the national and global level, indicating that there is a scope to enhance yields of different seed spice crops and their quality. More specifically, in case of fenugreek, the leading state in productivity is Uttarakhand (6525 kg ha^{-1}), followed by

Gujarat (2654 kg ha^{-1}). However, in terms of productivity, even after having the highest area under fenugreek in the country, Rajasthan occupies the fourth rank with a productivity of 1061 kg ha^{-1} only which is below the national average (1239 kg ha^{-1}). This is basically because of a significant gap between actual and potential yield of crop which is still grown by the traditional system of cultivation (Singh and Singh, 2013). There is, therefore, a need for minimizing the yield gap by enhancing the technical efficiency of the producers. The motivation for undertaking the study stemmed from the hypothesis that there exists an immense scope for improving the productivity of fenugreek production by technological advancement or by enhancing the technical efficiency that is, getting maximum yield from given level of inputs. In this regard, it is necessary to quantify current levels of technical efficiency so as to estimate losses in production that could be attributed to inefficiencies in production process due to differences in socio-economic characteristics and management practices. There is a plethora of empirical work on the efficiency of seed spices production in India. This paper deals with estimation of technical efficiency of fenugreek production and also identifies the key variables determining inefficiency. This study will contribute to the technical efficiency literature, especially for spices in general and seed spices in particular.

MATERIALS AND METHODS

Data and sampling framework

The Sikar district of Rajasthan State, which is located in the semi-arid part of the state was selected purposively for the study on the account of being one of the leading districts in fenugreek production in the state. Out of seven *tehsils*, two viz. Sikar and Sri Madhopur were selected randomly and from each of them, two villages chosen for the study. Finally, from all the four villages, 40 farmers from each category that is, small, medium and large were selected. Thus, the final data set encompasses a total of 120 observations. The data was collected by personal interview of the selected respondents using a pre-tested schedule designed particularly for this study.

Analytical tool

The two most commonly used techniques for estimating a production frontier and predicting maximum possible farm output are data envelopment analysis (DEA) and stochastic frontier analysis (SFA) (Coelli, 1996a, 1996b; Kontodimopoulos et al., 2010). Stochastic production frontiers were first developed by Aigner et al. (1977) and Meeusen and van den (1977). The specification allows for a non-negative random component in the error term to generate a measure of technical inefficiency, or the ratio of actual to expected maximum output, given inputs and the existing technology. DEA is a non-parametric approach that involves the use of linear programming to construct a frontier. It does not require assumptions concerning the form of the production function (Coelli, 1996b). The best practice production function is created empirically from observed input and output. It does not

identify the difference between technical inefficiency and random error (Admassie and Matambalya, 2002; Vu, 2003; Coelli et al., 2005). On the other hand SFA is a parametric approach, where the form of the production function is assumed to be known or is estimated statistically. It also allows other parameters of the production technology to be explored (Coelli, 1996a; Greene, 2003; Coelli et al., 2005). The advantages of this approach are that hypotheses can be tested with statistical rigour, and that relationships between input and output follow known functional forms. SFA enables the simultaneous estimation of technical efficiency and a technical inefficiency effects model (Admassie and Matambalya, 2002; Coelli et al., 2005). The technical efficiency of a farm is a comparative measure of how well it actually processes inputs to achieve its outputs, as compared to its maximum potential for doing so, as represented by its production possibility frontier. Thus, technical efficiency of the farm is its ability to transform multiple resources into output. A farm is said to be technically inefficient if it operates below the frontier. The coefficients of the production frontier and technical inefficiency effects model can be measured using the maximum likelihood method under the assumption of a normal distribution for U_i (Coelli et al., 2005; Tran et al., 2008). The appropriateness of the stochastic frontier approach can be tested by calculating the value of the parameter γ which contains a value between 0 and 1 and depends on two variance parameters of the stochastic frontier function. This is defined as follows (Battese and Corra, 1977; Coelli et al., 2005):

$$\gamma = \frac{\sigma_u^2}{\sigma^2}$$

Where, $\sigma^2 = \sigma_v^2 + \sigma_u^2$, where σ_v^2 and σ_u^2 are variances of the noise and inefficiency effects. If the value γ is close to zero deviations from the frontier are attributed to noise, whereas a value close to unity indicates that deviations are ascribed to technical inefficiency (Coelli et al., 2005; Tran et al., 2008).

Model

A Cob-Douglas production function using the cross-sectional data may be expressed as follows (Coelli 1996a):

$$y_i = \beta_0 + \beta_1 ln\, x_1 + \beta_2 ln\, x_2 + \beta_3 ln\, x_3 + \beta_4 ln\, x_4 + \beta_5 ln\, x_{i5} + (v_i - u_i); i = 1,2, \ldots \ldots \ldots N$$

$y =$ Yield (kg ha^{-1}), $x_1 =$ Seed rate (kg ha^{-1}), $x_2 =$ Machinery use (Man-days ha^{-1}), $x_3 =$ Human labour (hour ha^{-1}), $x_4 =$ Urea (kg ha^{-1}), $x_5 =$ DAP (kg ha^{-1}a).

Technical inefficiency model

$$u_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 D_1 + \delta_3 Z_4 + \delta_5 D_2$$

Z_1=Age of the household head (years), Z_2= Education level of the household head (average number of schooling years), Z_3= Family size (number of family member who are more 14 and less than 60 years), Z_4=Farm size (ha) , D_1= Dummy variable (1, if contact with extension worker, otherwise zero), D_2= Dummy variable (1, if resides at farm, otherwise zero).

The parameters of the stochastic frontier production function model were estimated by the maximum likelihood estimation (MLE) method using FRONTIER Version 4.1 (Coelli, 1996a).

Hypothesis tests

The estimation of a stochastic frontier production function can be used to test the validation of three hypotheses as follows: (1)

Table 1. Summary statistics of variables of stochastic frontier product (per ha).

Variable	Units	Small		Medium		Large		Overall	
		mean	SD	mean	SD	mean	SD	mean	SD
Output	kg	1888	7.75	1560	7.87	1272	6.67	1576	7.81
Human labour	Man-days	70.52	11.04	67.54	12.36	59.70	10.12	65.97	12.03
Machine use	hour	23.81	19.29	21.33	3.00	20.95	3.42	22.04	11.46
Irrigation	hour	69.74	7.92	48.74	22.19	43.05	8.69	53.84	18.6
Seed	kg	26.04	10.05	28.84	9.10	22.66	4.01	25.87	8.5
Urea	kg	38.84	11.35	26.78	9.35	25.71	9.27	30.44	10.66
DAP	kg	29.98	7.67	27.99	8.7	26.02	8.41	28.00	8.36

Source: field survey.

adequacy of the Cobb-Douglas production functional form; (2) absence of technical inefficiency effects; and (3) insignificance of joint inefficiency variables. Formal hypotheses tests associated with the stochastic production function and technical inefficiency effects models are presented in Tables 2, 3 and 4, respectively. Three hypothesis tests are conducted by using the generalised likelihood-ratio test (LR test), which can be defined as (Coelli et al., 2005; Tran et al., 2008; Amornkitvikai and Harvie, 2011):

$$\lambda = -2 \{ Log\ [L(H_0)] - Log[L(H_1)]$$

Where, $L(H_0)$ and $L(H_1)$ are the values of a log-likelihood function for the frontier model under the null hypothesis H_0 and the alternative hypothesis H_1. The LR test statistic contains an asymptotic chi-square (χ^2) distribution with parameters equal to the number of restricted parameters imposed under the null hypothesis(H_0), except hypotheses (2) and (3) which contain a mixture of a chi-square (χ^2) distribution (Kodde and Palm, 1986). Hypotheses (2) and (3) involve the restriction that λ is equal to zero which defines a value on the boundary of the parameter space (Coelli, 1996a). The paper estimates technical efficiency of fenugreek farming in the arid zone of Rajasthan, with the following hypotheses: The technical efficiency of fenugreek cultivating farms is invariant to farm-size; and technical inefficiency is dominated by random factors beyond the control of farmers.

RESULTS AND DISCUSSION

The mean level of output and input usages are presented in Table 1. The mean use of human labour, machinery and irrigation use were 66 man-days, 22 and 54 h per ha, respectively. Similarly, average amount of seed, urea and DAP applied were 26, 30 and 28 kg per ha, respectively. Highest level of output (1888 kg) was obtained at small farms and declines with increasing in farm sizes with average output of 1576 kg ha^{-1}. Analysis of socio-economic characteristics of the respondents revealed that the average farm size of small, medium and large farmer was to the extent of 1.17, 2.93 and 6.06 ha, respectively with overall size of 3.36 ha in the study area. The education level was observed to be 6.3 (Table 2).

Overall, around 60% of the farmers were in regular contact with extension personnel or agency. Among different categories, around 72% of the large farmers, highest among the three, had contact with an extension personnel or agency. About 37% of the farmers had their residence at the farm itself (*Dhani** - a local word which means dwelling at the farm).

Testing hypotheses

The first null hypothesis explores H_0: γ =0, which specifies that the technical inefficiency effects are not present in the model that is, fenugreek producing farms are perfectly efficient and have no room for efficiency improvement. The resulting likelihood ratio test of 54.84 leads to rejection of the null hypotheses in favour of the presence of inefficiency effects in the model at 5% level of significance (Table 3). Thus, the traditional average response function is not an adequate representation of the data and inclusion of the technical inefficiency term is a significant addition to the model. The second null hypothesis is regarding the distribution assumption that the inefficiency component of the random error term follows. H_0: μ = 0, specifies that a simpler half-normal distribution is an adequate representation of the data, given the specifications of the generalized truncated-normal distribution. The test statistic of 6.19 leads to rejection of the null hypothesis at 1% level of significance and therefore truncated normal distribution is more appropriate for the fenugreek producing farmers. The third null hypothesis which was tested is; $H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$ implying that the farm-level technical inefficiencies are not affected by the farm-oriented variables included in the inefficiency model. This hypothesis is also rejected, implying the variables present in the inefficiency model have collectively significant contribution in explaining technical inefficiency effects. However, it has expected sign that is, negative, but it was statistically insignificant. The high value of gamma (0.915) indicated the presence of inefficiency in the production of crop. This significance higher value of gamma indicates the appropriateness of applying SFA model. If the coefficient of gamma was not significant, an OLS function would have been sufficient, as the

Table 2. Socio-economic variables of the sample farmers.

Particulars	Units	Small	Medium	Large	Overall
Age	Number of years	46.5	48.5	48.7	47.9
Education	Average number of schooling years	5.6	5.6	7.6	6.3
Extension	% farm having contact to extension personnel/agency	53	56	72	60
Family size	Number of working persons in family	4.00	5.00	4.00	4.00
Farm size	ha	1.17	2.93	6.06	3.36
Residence	% farmers living at farm	46	30	34	37

Source: field survey.

Table 3. Different hypotheses, respective decisions and their implications.

Null hypothesis	Test statistic	Decision	Implication
$H_o : \gamma = 0$	54.84**	Rejected	Use stochastic frontier model instead of ordinary least square model
$H_o : \mu = 0$	6.19***	Rejected	Assume truncated normal distribution
$H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$	251.90***	Rejected	Include joint inefficiency determining variables

component technical inefficiency is small (Battese and Coelli, 1995). About 92% of the difference between the observed and the frontier value productivity was due to the presence of inefficiency, mainly through the non-judicious use of resources, which was under the control of sample farmers.

Parameter estimates of stochastic production frontier

The maximum likelihood estimates of stochastic production frontier for Cobb-Douglas form under truncated-normal distribution of u_i have been presented in Table 4. The variables having positive and significant coefficients were irrigation, DAP and urea use. This implies that there is potential for increasing fenugreek production by raising the quantity of some inputs. Irrigation, particularly, is an important input which enhances the fertilizer use efficiency. More precisely, one per cent increase in the use of irrigation, urea and DAP will result into 0.14, 0.01 and 0.26% increase in the output.

Thus, it seems that irrigation-fertilizer interaction has a positive impact on the yield. The variable seed was observed to be with a negative coefficient (but statistically insignificant) which shows that seeds are being over-utilized. The summation of the coefficients is less than one which indicates that at present, in general, farmers were observed to be working at decreasing returns to scale which amounts to saying that use of some inputs exceeded scale efficient level of quantities for the existing technology.

Determinants of inefficiency

Age of the farmer exhibited a negative coefficient which is significant at 1% level (Table 4). This implies that with an increase in age the technical inefficiency declines. The results of this study support the findings of Bravo-Ureta and Pinheiro (1997); Abdulai and Eberlin (2001) and Mondal et al. (2012). It further reveals that experienced farmers are relatively more efficient or had a better understanding of resource uses with respect to amount and combination of inputs along with timing of their application. Education also was found to have a negative effect on the technical inefficiency which means schooling has a positive bearing on the technical efficiency, since education enhances the decision making capability and understating about the technical know-how (Kaura et al, 2010). The education not only helps in better crop management decisions but also facilitate in availing better agricultural related services (Tilak, 1993). Similarly, contact with an extension person/agency had a positive impact on the technical efficiency and farmers get to know about the suitable variety, pest and disease control measures and agronomic practices etc. Coefficient associated with the farm size had a positive sign which shows that large farms are technically inefficient than their smaller counterparts. This is mainly attributed to non-uniform and insufficient application of irrigation water given the same duration of electricity supply to farms. Therefore, large farmers with a single tube-well are forced to prioritize irrigation to wheat, which occupies a large area in cropping pattern of large farmers as compared to smaller farms. Therefore, timely availability

Table 4. Maximum likelihood estimates of stochastic frontier model.

Parameter	Coefficient	Standard error
Stochastic production frontier		
Intercept	1.203	0.349
Seed	-0.046	0.043
Human labour	0.051	0.063
Irrigation	0.137**	0.056
Machinery use	0.041	0.043
Urea	0.091*	0.055
DAP	0.261***	0.050
Inefficiency effects		
Intercept	1.197	0.346
Age	-0.202***	0.031
Education	-0.009*	0.005
Extension contact	-0.215***	0.020
Family size	0.199***	0.118
Farm size	0.007*	0.013
Residence status	-0.007	0.013
Variance parameter		
Sigma-squared	0.064**	0.013
Gamma	0.915***	0.022

***, ** and * indicate the level of significance at 1, 5 and 10%.

Table 5. Descriptive statistics of technical efficiency.

Particular	Small	Medium	Large	Overall
Mean	0.78	0.69	0.63	0.70
Standard deviation	0.28	0.30	0.26	0.28
Minimum	0.17	0.17	0.15	0.15
Maximum	0.98	0.98	0.99	0.99

The null hypothesis, $H_0 : \overline{X_s} = \overline{X_m} = \overline{X_l}$, which was rejected at 5% level of significance. This null hypothesis suggests that mean technical efficiency scores are same for all farm categories. $\overline{X_s}$, $\overline{X_m}$ and $\overline{X_l}$ stand for the mean technical efficiency scores for small, medium and large farmers, respectively.

of water also provides incentive, especially to smaller farms, to apply fertilizers for fenugreek production, which in turn results in higher yield/ higher technical efficiency. In case of variable 'residence at farm', it was expected that farmer dwelling in a *Dhani* would be more efficient as they can start their farm work early in the morning and also can do the same late in the evening, since the farmers residing in village have to travel to their farm every day.

Mean technical efficiency and frequency distribution of farmers

The mean technical efficiency score was estimated to be 78, 69 and 63% for the small, medium and large farmers, respectively (Table 5). The mean technical efficiency scores were also different from each other at five percent level of significance. The overall average technical efficiency score was found to be 70% in the study area. This shows that there still exists a scope for increasing the output by 30% with the same levels of input. The minimum and maximum technical efficiency score were 15 and 99%, respectively.

Table 6 presents the distribution of farmers in different groups of technical efficiency ranges. Overall, in the region, around 52% fall in the higher efficiency range which indicates that farmers are following uniform practices for fenugreek cultivation. Further, about 72.5, 50.0 and 32.5% of small, medium and large farmers, respectively

Table 6. Distribution of farmers in different ranges of technical efficiencies (% farmers).

Particular	Small	Medium	Large	Overall
0-20	5.0	12.5	10.0	9.2
20-40	17.5	12.5	17.5	15.8
40-60	2.5	10.0	20.0	10.8
60-80	2.5	15.0	20.0	12.5
>80	72.5	50.0	32.5	51.7
Total	100	100	100	100.0

The null hypothesis, H_0 : F(S)=F(M)=F(L), which was rejected at 5% level of significance. This null hypothesis suggests that frequency distribution of all the farm categories is same. F(S), F (M) and F (L) stand for the frequency distribution of farmers belonging small, medium and large farmers.

were observed to be in a more than 80% of technical efficiency range. The F-test showed that the distribution of farmers in defined ranges is significantly different among one another at five percent level of significance.

Conclusions

The average technical efficiency in fenugreek production was observed to be 70%. This implies that there is scope for increasing the output by 30% with the same level of input uses. Further, smaller farmers were observed to be more efficient than the larger famers. The higher technical efficiency is mainly attributable to irrigation which in turn enhances fertilizer use efficiency. In general, farmers were found to be working at decreasing returns to scale which implies that quantities of some inputs exceeded scale efficient level of input uses as for the existing technology. This provides scope for optimal use of some inputs that would lead towards minimizing the cost of production and hence enhance efficiency. Experienced, educated farmers and those in contact with extension worker/agency are more efficient. There is a need to speed up extension programmes for the better production and use of scarce inputs. Since irrigation has a positive impact on the production, use of micro-irrigation, since the state is facing ever depleting level of groundwater, will ensure better utilization of scarce groundwater resources as well as sustainable production of crop.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Abdulai A, Eberlin R (2001). Technical efficiency during economic reform in Nicaragua: Evidence from farm household survey data. Econ. Syst. 25(2):113-125. http://dx.doi.org/10.1016/S0939-3625(01)00010-3

Admassie A, Matambalya F (2002). Technical efficiency of small-and medium-scale enterprises: evidence from a survey of enterprises in Tanzania. Eastern Afr. Soc. Sci. Res. Rev. 18(2):1-29. http://dx.doi.org/10.1353/eas.2002.0007

Agarwal S, Sastry EVD, Sharma RK (2001). Seed spices production, quality, export. Jaipur: Pointer Publishers.

Aigner DJ, Lovell CAK, Schmidt P (1977). Formation and estimation of stochastic frontier production function models. J. Econ. 6:21-37. http://dx.doi.org/10.1016/0304-4076(77)90052-5

Amornkitvikai Y, Harvie C (2011). Finance, ownership, executive remuneration, and technical efficiency: a stochastic frontier analysis (SFA) of Thai listed manufacturing enterprises. Austr. Acc. Bus. Finan. J. 5(1):35-55.

Battese GE, Coelli TJ (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. Empir. Econ. 20:325-332. http://dx.doi.org/10.1007/BF01205442

Battese GE, Corra GS (1977). Estimation of a production frontier model: with application to the pastoral zone of eastern australia. Austr. J. Agric. Econ. 2:169-179. http://dx.doi.org/10.1111/j.1467-8489.1977.tb00204.x

Bravo-Ureta BE, Pinheiro AE (1997) Technical, economic, and allocative efficiency in peasant farming: evidence from the Dominican Republic. Develop. Econ. 35(1):48-67 http://dx.doi.org/10.1111/j.1746-1049.1997.tb01186.x

Coelli TJ (1996a). A Guide to FRONTIER Version 4.1: a computer program for stochastic frontier production and cost function estimation, Working paper 96/07, Centre for Efficiency and Productivity Analysis, Armidale, University of New England.

Coelli TJ (1996b). A Guide to DEAP Version 2.1: a data envelopment analysis (Computer) Program, Working paper 96/08, Centre for Efficiency and Productivity Analysis, Armidale, University of New England.

Coelli TJ, Rao DSP, O'Donnell CJ, Battese GE (2005). An introduction to efficiency and productivity analysis, 2nd edn. Springer, New York.

Greene W (2003). Simulated likelihood estimation of the normal-gamma stochastic frontier function. J. Prod. Anal. 19:179-190. http://dx.doi.org/10.1023/A:1022853416499

Indiastat (2012) http://www.indiastat.com/agriculture/2/spices/262/fenugreek/20663/stats.aspx

Kaura M, Mahal AK, Sekhon MK, Kingra HS (2010). Technical Efficiency of Wheat Production in Punjab: A Regional Analysis. Agric. Econ. Res. Rev. 23:173-179

Kodde DA, Palm FC (1986). Wald criteria for jointly testing equality and inequality restrictions. Econometrica, 54(5):1243-1248. http://dx.doi.org/10.2307/1912331

Kontodimopoulos N, Papathanasiou ND, Flokou A, Tountas Y, Niakas D (2010). The impact of non-discretionary factors on DEA and SFA technical efficiency differences. J. Med. Syst.

Mathur P, Choudhry M (2009). Consumption pattern of fenugreek seeds in Rajasthani families. J. Hum Ecol. 25(1):9-12.

Meeusen WJ, van den B (1977). Efficiency estimation from Cobb-

Douglas production functions with composed error. Int. Econ. Rev. 18:435-444. http://dx.doi.org/10.2307/2525757

Mondal B, Singh A, Jha GK (2012) Impact of watershed development programmes on farm-specific technical efficiency: A study in Bundelkhand region of Madhya Pradesh Agric. Econ. Res. Rev. 25(2):299-308.

Pruthi JJ (2001). Minor spices and condiments crop management and post harvest technology. Directorate of Information and Publication of Agriculture. New Delhi: ICAR.

Singh R, Singh B (2013). Precision farming technologies for vegetables and seed spices crops for enhancing yield and quality, paper presented at National Symposium on Abiotic and Biotic Stress Management in Vegetable Crops, Indian Society of Vegetable Science January, 10.

Tilak TBG (1993). Education and agricultural productivity in Asia: A review. Indian J. Agric. Econ. 48(2):187-200.

Tran TB, Grafton RQ, Kompas T (2008). Firm efficiency in a transitional economy: Evidence from Vietnam. Asian Econ. J. 22:(1)47-66.

Vu QN (2003). Technical efficiency of industrial state-owned enterprises in vietnam. Asian. Econ. J. 17(1):87-101.

Full Length Research Paper

Defining corporate social responsibility in the South African agricultural sector

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Although corporate social responsibility (CSR) is an established research field worldwide, to date there is no single definition that is universally accepted. For this article, generally accepted models, principles and definitions regarding CSR were combined with the view of the South African government on CSR in order to propose a number of normative criteria for CSR in South Africa. The agricultural sector in South Africa has a specific sector charter called AgriBEE that guides their CSR activities. A comparison of the above-mentioned criteria with the AgriBEE indicator for Corporate Social Investment (CSI) indicates that agricultural organisations will not live up to these theoretical criteria should they continue to adhere to AgriBEE CSI, since there is a discrepancy between what is expected from companies as part of CSI in AgriBEE and the normative criteria for CSR. On the other hand, the AgriBEE indicator for enterprise development (the indicator focused on an agricultural organisation's assistance to emerging black farmers) has much in common with the set normative CSR criteria. Through the case study of a company from the agricultural sector, it is concluded that although Senwes terms their approach enterprise development, the company applies the proposed normative criteria for CSR through their enterprise development activities.

Key words: Corporate social responsibility (CSR), corporate social investment (CSI), governance, AgriBEE, land reform, Senwes, enterprise development.

INTRODUCTION

Land reform in South Africa

Land reform in South Africa became a burning issue with the abolition of apartheid and the transformation into a democratic dispensation and was necessitated by the extreme unequal distribution of land (Lahiff, 2008). Through its inclusion in Section 25 of the Constitution of the Republic of South Africa (1996), land reform received a constitutional basis from which the reform agenda could be driven (Miller and Pope, 2000). Section 25 of the Constitution established restitution, redistribution and tenure reform as the three land reform programmes. The restitution programme is facilitated through the Restitution of Land Rights Act (22/1994), an act aimed at enabling historically disadvantaged South Africans to claim redress for the disposition of land that they suffered because of past racially discriminatory laws and practices.

Since the process of restitution has almost been completed[1] and tenure reform is focused on providing secure tenure for those whose tenure is insecure because of past discriminatory laws or practices [Section 25(6)], the scope of this article is limited to the redistribution programme. In terms of Section 25(5), the state is under a constitutional obligation to take reasonable legislative and other measures, within the scope of its resources, to create conditions that would enable historically disadvantaged citizens to gain access to land on an equitable basis. In this regard, Government set the target of transferring 30% of white-owned agricultural land to historically disadvantaged South Africans by 2014 (De Villiers, 2008; Lahiff, 2008).

The aim of this redistribution is to enable black people to enter into the economy through the use of agricultural land for agricultural activities.[2] The success of the redistribution programme is, however, in dispute as a large number of redistribution programmes have failed because they have not been able to facilitate sustainable livelihoods and consequently pose a threat to a sustainable economy (De Villiers, 2008; Lahiff, 2008). The reasons for the failure of these programmes include a lack of post-settlement support from Government, a lack of access to capital from financial institutions and a lack of skills to manage and maintain a farm as a productive agricultural unit (De Villiers, 2008; Lahiff, 2008). Those who intended to benefit from Government's redress programmes (particularly black emerging farmers in terms of the redistribution programme) often do not have the necessary skills to utilise the resources at their disposal. In the case of land reform, beneficiaries are often resettled on agricultural land and are expected to engage in agricultural activities, but do not have the necessary knowledge and farming skills to make a success thereof (De Villiers, 2008).

The role of agribusiness in the success of land reform

From these problems, it is evident that the situation needs to be addressed urgently in order to avert an economic crisis. In this regard, the agribusiness sector is strategically situated in order to contribute not only to the empowerment of those disadvantaged by the apartheid regime, but also to the overall success of the redistribution programme. There is a need for specialists in the field of agriculture to assist these emerging farmers to enable them to become commercial farmers who can create sustainable livelihoods for themselves and their families and eventually contribute to the national food basket.

The idea of business sectors such as the agribusiness sector providing assistance to emerging farmers is supported by the King Report on Corporate Governance for South Africa 2002, which indicates that organisations need to invest in society in order to promote the greater well-being of society at large (IOD, 2002). This sentiment is also echoed by the King III report published in 2009, stating that organisations are corporate citizens who should respond to social challenges (IOD, 2009). One way in which an organisation could contribute to society is through the acceptance of its social responsibility and resulting corporate social responsibility (CSR) initiatives.

Corporate social responsibility

CSR has been practised and studied worldwide since the early 1950s (Carroll, 2008; De Bakker et al., 2005). Despite this, there is no universally accepted definition of CSR (Carroll, 2008; Cutlip et al., 1985; Crowter and Aras, 2008).

Over the last ten to fifteen years, CSR has become increasingly important in South Africa (SAGA, 2002; AICC, 2005; Fig, 2007). Although the term *CSR* is widely used amongst practitioners and academics, South African businesses prefer the term *corporate social investment* (CSI) (Fig, 2005). South African businesses appear to be uncomfortable with the term *responsibility*, arguing that this implies that they are responsible for the injustices of the past and have a responsibility to offer redress for the human rights violations under the apartheid regime (Fig, 2005). In this article, the term CSR is used unless otherwise specified in documents consulted.

Until recently, CSR was an entirely voluntary activity in South Africa (Trilogue, 2005). However, the introduction of the Broad-based Black Economic Empowerment Act, various industry transformation charters, the Codes of Good Practice by the Department of Trade and Industry, the King II and III report on Corporate Governance, the ISO 26 000 Guidance on Social Responsibility and the new Companies Act (effective from 2011) should compel South African companies to implement CSR.

The Broad-based Black Economic Empowerment Act forms one of the cornerstones of development in South Africa and was promulgated against the background of the history of apartheid in South Africa. The aim of the Act is to "promote the achievement of the constitutional right to equality, increase broad-based and effective participation of black people in the economy and promote a higher growth rate, increased employment and more equitable income distribution" (SA, 2005). It is clear from this, that deliberate action is to be taken if this is to be realised. Corporate social responsibility initiatives can be regarded as in instrument through which this can be achieved.

Within the South African context, the lack of a clear definition of CSR and lack of relevant literature focusing

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[1] By 2008, approximately 95% of all land claims had been settled (De Villiers, 2008:4–5).
[2] Section 1 of the Black Economic Empowerment Act (53/2005) defines 'black' as a generic term that refers to Africans, Coloureds and Indians.

on South Africa (or other developing countries) complicates the successful implementation of CSR. In practice, requirements specific to the business sector are being formulated that are often in conflict with universal normative requirements of CSR. As indicated, the agricultural sector is required by AgriBEE to engage in CSI activities. However, the definition of CSI in AgriBEE differs considerably from widely accepted definitions of CSR. This leaves the company with the dilemma of which guidelines to follow. Against this background, this article explores how CSR can be defined within the South African Agricultural sector, by examining generally accepted definitions, as well as the guidelines provided for in AgriBEE. Senwes and its CSR activities is used as a case study to illustrate the dilemma of companies in the agricultural sector trying to adhere to both AgriBEE and universal normative requirements for CSR.

RESEARCH METHOD

This article was approached in a qualitative way, in order to gain insight into a relative new field of study. A literature study was performed to identify the normative criteria for CSR in South Africa against the backdrop of land reform in the country. The empirical information was collected through a semi-structured interview with the *Manager: Agricultural Services* of Senwes, as well as through analysis of policy documents and other relevant documents from Senwes, including some of the company's annual reports, informational documents and presentations delivered relevant to the subject. All the gathered information was analysed through qualitative content analysis, using the normative criteria for CSR as the units of analysis.

RESULTS AND DISCUSSION

Corporate social responsibility in South Africa: Theoretical assumptions

As indicated in the introduction, South African companies are increasingly under pressure to engage in CSR activities because of the requirements set by the BEE framework. In this article, the, (1) three-domain model of Schwartz and Carroll (2003); (2) notion of strategic CSR as proposed by Lantos (2001); (3) Principles of CSR as identified by Crowter and Aras (2008); (4) European Union Commission's (2002) definition of CSR; (5) International Organisation for Standardization (2010) definition of CSR and (6) South African government's view on CSR in South Africa (2005) are being combined to formulate a number of normative criteria for CSR in South Africa.

The three-domain model of Schwartz and Carroll (2003), based on Carroll's four-domain model (1979), is widely recognised as a model for evaluating an organisation's CSR activities. This model proposes that organisations have an economic, legal and ethical responsibility towards society (Schwartz and Carroll, 2003). The economic aspect includes all the actions

aimed at a direct or indirect positive economic impact on the organisation. Lantos (2001) strongly supports this notion and stresses that CSR should be a *strategic function* of organisations. The legal aspect relates to the organisation's responsiveness to the legal expectations to which the organisation should adhere. The ethical aspect focuses on the ethical expectations of an organisation held by society and all relevant stakeholders (Schwartz and Carroll, 2003).

Although not a formal definition, Crowter and Aras (2008) propose three basic principles that underlie all CSR activity: *Sustainability, accountability* and *transparency*. It is argued that society should not use more resources than can be renewed (sustainability), that organisations should acknowledge their impact on the external environment and report the manner in which they are accepting their responsibility and fulfilling it with regard to stakeholders' expectations (accountability), and that the impact of an organisation's actions (positive and negative) should be evident from its reporting and not be disguised (transparency).

The European Union Commission (2002) definition is widely accepted and quoted and states that "CSR is a concept whereby companies integrate social and environmental concerns in their business operations and in their interactions with their stakeholders on a voluntary basis". It is clear from this definition that organisations should consider social and environmental issues regarding all their actions. It thus supports the reasoning of Schwartz and Carroll (2003) as well as Crowter and Aras (2008).

In 2010 the International Organisation for Standardization (ISO, 26000:2010) published a document called Guidance on social responsibility in which CSR was defined as "the responsibility of an organisation for the impacts of its decisions and activities on society and the environment, through transparent and ethical behaviour that: contributes to sustainable development, including health and the welfare of society; takes into account the expectations of stakeholders; is in compliance with applicable law and consistent with international norms of behaviour; and it integrated throughout the company and practised in its relationships". This definition was approved and adopted by both the South African National Standard (2010) and the King III report (2009) which makes it a very relevant and important definition of CSR in South Africa.

In defining CSR in the South African context, the definition adopted in the Draft Codes of Good Practice on Broad-Based Black Economic Empowerment could be used as a further guideline. This definition states that social investment (as it was referred to in the document) is "an enterprise's contributions to society and community that are extraneous to its regular business activities" (Department of Trade and Industry, 2005). This definition furthermore emphasises development as the outcome of CSR and that local communities should be the main beneficiaries of these programmes.

Based upon consideration of the above-mentioned guidelines and principles, the following normative theoretical criteria for evaluating CSR programmes are proposed. CSR programmes in South Africa should be:

1. Reflecting the company's responsibility for its impacts and activities on society;
2. Extraneous to the company's regular business activities;
3. Focused on sustainable development and assist development initiatives;
4. Beneficial to local communities of companies as well as society at large;
5. considering the economic, legal and ethical responsibility of the organisation;
6. Strategically aligned with the goals of the organisation;
7. Addressing social and environmental concerns; and
8. Sustainable, transparent and demonstrate that the company is accountable.[3]

These criteria are informed by generally accepted definitions and principles of CSR. In the South African context, however, there as specific requirements regarding CSR (and by implication definitions of CSR) for specific sectors. Those requirements pertinent to the agricultural sector as discussed subsequently.

The agricultural sector and corporate social responsibility

The Broad-based Black Economic Empowerment Transformation Charter for Agriculture (AgriBEE; Department of Trade and Industry, 2008) is of relevance to the agricultural sector. The aims of AgriBEE are to "facilitate broad-based black economic empowerment in the agricultural sector by implementing initiatives to include Black South Africans at all levels of agricultural activity and enterprises along the entire agricultural value chain by:

1. Promoting equitable access and participation of Black people in the entire agricultural value chain;
2. De-racialising land and enterprise ownership, control, skilled occupations and management of existing and new agricultural enterprise;
3. Unlocking the full entrepreneurial skills and potential of Black people in the sector;
4. Facilitating structural changes in agricultural support systems and development initiatives to assist Black South Africans in owning, establishing, participating in

and running agricultural enterprises;
5. Socially uplifting and restoring the dignity of Black South Africans within the sector;
6. Increasing the extent to which communities, workers, co-operatives and other collective enterprises own and manage existing and new agricultural enterprises, increasing their access to economic activities, infrastructure and skills training;
7. Increasing the extent to which Black women, people living with disabilities and youth own and manage existing and new agricultural enterprises, increasing their access to economic activities, infrastructure and skills training
8. Empowering rural and local communities to have access to agricultural economic activities, land, agricultural infrastructure, ownership and skills."

According to AgriBEE, indicators of empowerment are ownership, management control, employment equity, skills development, preferential procurement, enterprise development and CSI (Department of Trade and Industry, 2008). An organisation's performance regarding these indicators is measured through a generic AgriBEE scorecard for which each of these indicators has the following weighting (Department of Trade and Industry, 2008):

1. Ownership: 20%
2. Management control: 10%
3. Employment equity: 10%
4. Skills development: 20%
5. Preferential procurement: 20%
6. Enterprise development: 10%
7. CSI: 10%

In order to highlight the complexity of defining CSR in the agricultural context, both the CSI and enterprise development indicators are discussed. Although the scorecard refers to CSI, the AgriBEE charter does not provide a definition for CSI. Instead, it provides a definition for social economic development – although this term is not used in the scorecard.

According to AgriBEE, the CSI indicator (Department of Trade and Industry, 2008) indicates an agricultural organisation's contribution to social development and industry specific initiatives, for example:

1. Community educational facilities and specifically educational programmes aimed at agriculture, as well as community training programmes focusing on skills development as well as adult basic education and training (ABET);
2. Development programmes for sport, arts and culture aimed at the youth; and
3. Programmes focusing on the environment;
4. Programmes focussing on the creation of jobs in agriculture external to the organisation.

In comparing the requirements of the CSI indicator to the

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[3] Although the principles of accountability and transparency are very useful and should be part of the normative criteria for CSR, they will not be addressed in this article. Since the scope of this article is only on what is being done and not much attention is given to how they are communicating about or reporting on CSR and do not focus on the outcomes and results of Senwes' CSR programmes, these principles can not be effectively measured.

normative criteria set above for evaluating CSR, it is evident that there is a significant discrepancy between the two. In order to highlight this discrepancy, Senwes' CSI activities are evaluated against the AgriBEE indicator and the normative criteria for CSR.

The enterprise development indicator (Department of Trade and Industry, 2008) indicates an agricultural organisation's contributions to the core pillars of sustainable empowerment initiatives, for example:

1. The development of financial and operational capacity of black entrepreneurs;
2. The provision of mentoring, as well as access to inputs, credit, infrastructure, markers, technology and extensive services (mentoring refers to providing technical and/or general business assistance and support to black emerging farmers, the beneficiaries of land reform and black entrepreneurs);
3. The support of land reform beneficiaries and black persons through the transfer of specialised skills as part of mentorship programmes.[4]
4. Committing cumulative enterprise development contributions in order to assist and accelerate the development of black entrepreneurs, as a percentage of cumulative net profit after tax; and
5. Leasing agricultural land to black entrepreneurs.

In comparing the enterprise development indicator to the normative criteria set above for evaluating CSR, it would seem that the activities described under this indicator would actually fall within the realm of CSR. Therefore, for the purposes of this article, both Senwes' CSI and enterprise development activities were evaluated against the AgriBEE indicator under which the activities were reported on as well as the normative criteria for 'good' CSR.

Corporate social responsibility programmes at Senwes

Senwes is an agricultural organisation that celebrated its hundredth year of existence in 2009. Senwes is one of the leading agricultural service provider in South Africa and conducts business in the Free State, North West, Gauteng and Western Cape provinces (Senwes, 2011). The organisation conducts extensive activities in the agricultural sector, such as the grain industry, supply of farming inputs, the mechanisation market and providing financing focused on agriculture (Senwes, 2012a). The organisation's vision is to be the most admired agribusiness in South Africa (Senwes, 2012a) and its slogan *breaking new ground* highlights its vision of being an innovative company.

Senwes' strategy includes diversification within core

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[4] This support should be quantified in Rand value.

business, the unlocking of value, black economic empowerment (BEE) and financial performance (Senwes, 2012a). The inclusion of BEE in the organisational strategy emphasises the organisation's commitment to transformation and its support for the core objectives of the National Sector Plan for Agriculture, namely (Du Toit, 2009a):

1. Equitable access and participation;
2. Global competitiveness and profitability; and
3. Sustainable resource management.

According to the organisation's BEE policy (Senwes, 2012b), Senwes believes that black economic empowerment (BEE) and the implementation thereof is critical in addressing the injustices of the past and that it is a crucial driver of economic and social transformation in South Africa. The company pledge their support for BEE and are committed to aligning their business with the national transformation agenda.

With regard to the stakeholders of the organisation, Senwes claims that as a company that seeks to be the most admired agribusiness in South Africa, it focuses on creating value for all its stakeholders in accordance with their needs and expectations. The organisation lists its stakeholders as shareholders and investors, customers, employees, suppliers, the community and society, regulators and government. The company's approach to stakeholder engagement is based on the principles of transparency, and the purpose thereof is to broaden and deepen the company's understanding of their stakeholder's needs, expectations, concerns and perceptions relevant to the company (Senwes, 2011).

Senwes pledges to be a responsible corporate citizen and to contribute to the improvement and development of the quality of life of the community as well as to support sustainable community development initiatives in partnership with other role players (Senwes, 2012b). It thus appears that the company values its corporate responsibility. In the following section, Senwes' CSI activities are investigated.

Corporate social investment indicator

Senwes defines CSI as "a *license for business to operate in the society in which it operates. It is an investment in the community, so as to create an environment that is safe, healthy, secure, and conductive to do business"*. The company stresses its commitment to its employees, the community, environment and the sustainable development of the country and all its people (Senwes, 2012b).

For the indicator CSI, Senwes (2011) reported that the company engaged in various CSI initiatives with a focus on promoting sport. The first initiative is the *Spinners rural schools cricket development programme,* of which the aim is the introduction of cricket to rural schools in the

Senwes area by training players and coaches and providing playing kits. Further initiatives include, the *Senwes schools soccers league launched* in Bothaville, aimed at developing soccer in rural communities as well as the *Rural schools athletics programme* involving 12 rural schools.

Senwes is also involved in Community and Educational programmes, where the organisation assists selected NGOs and charity organisations with fund raising and an annual Christmas party. The company is also working in partnership with academic institutions in different ways, including a sponsorship to the North-West University and bursaries granted to deserving students in the field of agriculture (Senwes, 2011).

It is evident from evaluating these activities against the set normative criteria for CSR that they fall short of complete classification as CSR, although some of the requirements are met. All these activities are extraneous to the company's regular business activities, benefiting the local communities of the organisation and, if the development of sport is viewed as a social concern, the programmes address social concerns. With regard to the legal responsibility of the organisation, complying with AgriBEE can be viewed as fulfilling this responsibility.

These activities however, fall short compared to the normative criteria for CSR formulated in this paper. The CSI activities do not reflect the company's responsibility for its impacts and activities on society, one of the most important criteria for CSR. Furthermore, these activities also fail to meet important requirements of CSR since they are not truly focused on sustainable development; at best, the projects are focused on short-term skills acquirement, which if not strategically managed would not contribute to development. At the time of the study, there was no indication that these activities were aligned to development goals. In addition, the activities were not strategically aligned with the goals of the organisation. Coinciding with the lack of strategic alignment of the activities, they also did not hold any direct or indirect economic gain for Senwes and could therefore not be classified under the economic domain.

Although the company is putting effort into reducing its impact on the environment, these initiatives were not classified as part of CSI initiatives, therefore, the CSR activities did not address environmental concerns; neither can it be classified as truly fulfilling the organisation's ethical responsibility.

In comparing Senwes' CSI activities with the normative criteria set, it appears that they do not comply with the criteria for CSR. Of particular concern is the lack of strategic alignment with company goals and lack of sustainable development, which could benefit the company. This raises the question: What led to the selection of these seemingly unrelated activities in Senwes' definition of CSI? The answer lies in the proposed AgriBEE CSI initiatives. Since no clear definition is provided for CSR, companies only have their specific sector charters as a guide for their CSR initiatives. A comparison of Senwes' above-mentioned activities to the CSI indicator in AgriBEE demonstrates that the focus of these programmes is in accordance with what is expected from them. These activities focus on the youth, promotion of sport and, to a lesser extent, education.

As the definitions of CSR proposed by the literature and pertaining to the agricultural sector in particular differ so vastly, it would be incomplete to evaluate Senwes' programme without also analysing the enterprise development indicator, which is nearer to the definition of CSR as proposed in this article.

Enterprise development indicator

A strong and growing black entrepreneurship is vital to the success of BEE and Senwes is committed to assisting through facilitating the establishment and expansion of targeted sustainable and viable small and medium enterprises in the black community (Senwes, 2012b).

According to Du Toit (2009b), a commercial farmer is now required to be a production manager, a marketing manager, a financial manager and a personnel manager because commercial farming is a commercial business like any other. It is thus evident that emerging farmers are in need of assistance to empower them to become commercial farmers, particularly those farmers who do not have a background in agriculture, such as the majority of the farmers who received agricultural land through the land reform programme.

With regard to assistance to emerging farmers, Senwes claims to be committed to "making a positive contribution to the advancement and development of emerging commercial farmers who demonstrate commitment, integrity and have the aspiration to become fully fledged commercial producers within a reasonable space of time (three to five years)" (Du Toit, 2009a).

Senwes assists emerging farmers through "investments, facilitating access to capital, business resources, markets, linkages between big and small businesses, procurement, entrepreneurial and technial support and management development. Most specifically, Senwes is involved in the development of emerging black commercial farmers, through the provision of technical support, facilitation of access to capital, training, input supply and mentorship" (Senwes, 2012b).

Senwes' programme regarding assistance to emerging farmers is reported under the enterprise development indicator of AgriBEE. In the annual report for 2008 (Senwes, 2008), it is reported that Senwes focused their enterprise development efforts at emerging and developing farming enterprises, by rendering technical support to these farmers through the services of an agronomist, soil scientist, agricultural scientist and
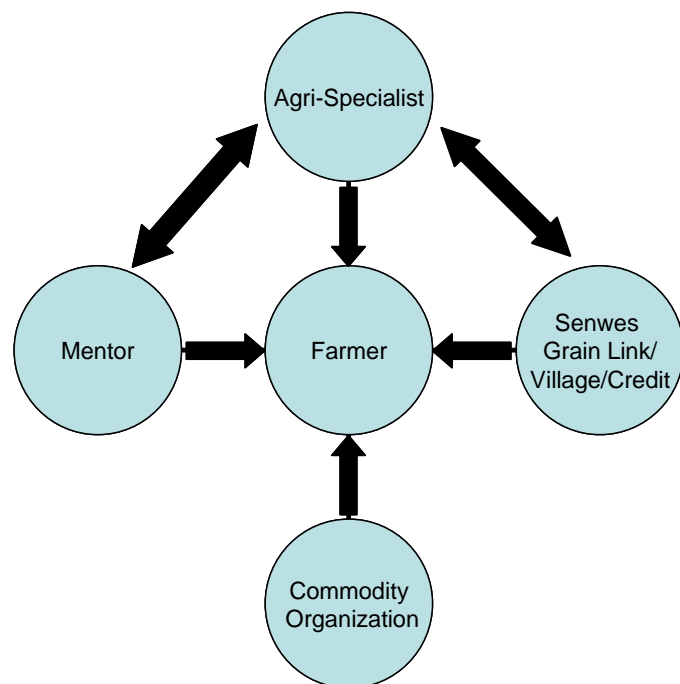
Figure 1. Model for assistance to emerging farmers. Source: Senwes presentation at Nampo, 2009 (Du Toit, 2009a).

livestock specialist. These farmers were provided with training programmes, production facilities and crop insurance. Furthermore, Senwes signed grain storage and off-take agreements with the farmers in order to ensure market access. Senwes also facilitates a mentor system through which experienced commercial farmers act as mentors by assisting emerging farmers. In the annual report for 2011 (Senwes, 2011), it is reported that Senwes focused their enterprise development efforts at" assisting farmers with technical support, production finance, training in order to ensure that the arable land in our area of operation is productive and that emerging farmers can run profitable farming enterprises through pursuing best farming practises".

Senwes' activities regarding support to emerging farmers are guided by several important principles (Du Toit, 2009a). Senwes aims to establish a mutually beneficial, long-term business relationship with emerging farmers, based on mutual respect, willingness, integrity and commitment. Senwes found that it was very difficult to provide comprehensive support to part-time farmers, owing to availability and commitment, and furthermore that farmers cannot commence on their own without a basic understanding or background of farming practices and entrepreneurial skills. It was also evident that experienced specialists in the field are needed to support emerging farmers effectively.

The goal of this programme is to provide support to farming units that have the potential to be viable and sustainable, and is predominantly based on the approach

of one farmer, one farm, since history has proved assistance to communities farming on a single farm as counterproductive. Skills transfer is based on practical assistance through the "learning by doing" principle and capacity building is based on the "continuous improvement" principle. Technical and financial support is based on comprehensive resources, competency and feasibility analysis, thus a multidisciplinary approach is adopted (Du Toit, 2009a).

Senwes adopts a hands-on approach in terms of monitoring progress and mitigation of risk through constant feedback from specialists to management, and mentoring is considered a key element to the success of the programme. A consultative buy-in approach is adopted, and the importance of constant communication and feedback is emphasised. In exchange for assistance, Senwes expects the emerging farmers to conduct business with Senwes, which includes the purchase of production inputs and marketing of grain (Du Toit, 2009a).

Even though they have experienced many challenges in this programme, Senwes views the commercialisation of developing farmers as a long-term process. The support of specialists who are dedicated to the process, have patience and perseverance and are equipped with exceptional communication and project management skills are crucial to the success of the programmes and land reform in general (Du Toit, 2009a).

According to Du Toit (2009a), it is important to ensure that every step in the process is followed in order to ensure a positive outcome. Firstly, it is crucial to determine the farmer's financial objectives, resource potential and enterprise feasibility and it is thus important that the service provider (Senwes) be part of the initial selection of candidates. The importance of the selection of suitable candidates is of utmost importance. The remaining steps of the process consist of the analysis and planning of assistance, application for funding and ensuring that the emerging farmer has a committed mentor. Senwes realises that support following training is essential and has a system through which ongoing support is provided and the progress of the farmer is continuously monitored. Formative and summative evaluation is implemented in order to ensure that the programme is constantly improved.

Figure 1 outlines the model Senwes follows in providing comprehensive assistance to emerging farmers (Du Toit, 2009a). From this figure, it is clear that assistance to emerging farmers is very comprehensive and that Senwes strives to ensure that these farmers receive all the assistance they may need to become productive commercial farmers.

Other activities reported on as part of enterprise development is the *Senwes Entrepreneurship Competition* focused in encourage entrepreneurship and developing entrepreneurial skills at school level. Senwes also initiated the *Senwes Young Farmers Future Focus* event aimed at developing and encouraging interest in agriculture,

Table 1. Comparison of the CSI initiatives and the enterprise development initiatives of Senwes with regards to the normative criteria for CSR in South Africa.

Normative criteria for CSR initiatives	Corporate Social Investment Initiatives	Enterprise development initiatives
Reflecting the company's responsibility for its impacts and activities on society	No	To some extent
Extraneous to the company's regular business activities	Yes	Yes
Focused on sustainable development and assist development initiatives	No	Yes
Beneficial to local communities of companies as well as society at large	Benefits local community, but not society at large	Yes
Considering the economic, legal and ethical responsibility of the organisation	Considers legal responsibilities, but not economic and ethical responsibilities	Yes
Strategically aligned with the goals of the organisation	No	Yes
Addressing social and environmental concerns	To some extent	Yes

as well as sharing new trends and developments in farm management with young and prospective farmers (Senwes, 2011).

In measuring the assistance to emerging farmers against the normative criteria for CSR, it is evident that these activities are extraneous to the organisation's regular business activities, focused on development, assisting development initiatives and for the benefit of some members of the organisation's local community. By undertaking these activities, from which the organisation will benefit economically in the long term, it is adhering to AgriBEE and thereby fulfilling its legal responsibility. By empowering farmers who were historically disadvantaged to provide for themselves and their families and eventually contribute to the economy, the organisation is acting ethically. Assistance to emerging farmers who may become commercial farmers who conduct business with Senwes is strategically aligned with the goals of the organisation. Furthermore, by empowering emerging black farmers, the organisation is addressing social concerns, such as poverty alleviation and empowerment.

In evaluating Senwes' enterprise development activities using the enterprise development indicator, it is clear that the company is contributing to the financial and operational capacity of black enterprises. Furthermore, the programme makes provision for mentoring, as well as access to credit, infrastructure, markets, technical support and other services. Senwes makes sizable financial contributions towards enterprise development.

It is thus clear that while the assistance to emerging farmers meets almost all the requirements of AgriBEE's enterprise development indicator, it also complies with the vast majority of normative criteria for CSR set in this article.

When comparing the results from the Senwes case study with the normative criteria for CSR in South Africa, one can see that Senwes' enterprise development initiatives are adhering to the criteria in almost all aspects, while the CSI initiatives adhere to the criteria in a much lesser extent (Table 1).

Since Senwes' CSI initiatives, as well as its enterprise development initiatives are in line with the guidelines prescribed in the AgriBEE documents, it can be concluded that with regard to the agricultural sector, the enterprise development indicator is much more in accordance with the general understanding of CSR than the CSI indicator.

Conclusion

It follows from the findings of this article that CSR is tremendously important in the agricultural sector, particularly regarding the support of emerging farmers. While the necessity of CSR is undisputed, the scope of CSR in South Africa is not clearly defined. AgriBEE, the charter that guides CSR in the agricultural sector, defines CSI in terms of programmes with a specific focus on youth, sport and job creation in the agricultural sector. Comparison of this view of CSR to the normative criteria as outlined in this article casts into doubt that the CSI indicator in AgriBEE relates to CSR, as there is no indication that the company should consider the development needs of its community or that the social concerns of the community should be addressed. The importance of sustainability is not mentioned and no attention is given to the transparency and accountability of the company. The company's economic, legal and

ethical responsibility is also not considered. Furthermore, the guidelines propose haphazard activities that are not strategically aligned with the goals of the company. However, from comparison of the definition of enterprise development as given in AgriBEE to the normative criteria for CSR, it appears that what is considered enterprise development indeed meets the majority of the criteria for CSR. Against this background, it is extremely difficult to evaluate the CSR activities of an agricultural company such as Senwes. When only its CSI programmes were evaluated, the sustainability of its CSR appeared questionable. However, when the enterprise development indicator was evaluated, it was evident that Senwes is managing a substantive CSR project supporting developing farmers. Senwes cannot be criticised regarding the content and aim of its CSR programme, since it is prescribed by AgriBEE.

Thus, this article advocates the revisiting of the AgriBEE's definition of CSR. Should there be no consensus regarding the definition of CSR, companies in the agricultural sector cannot be expected to practise normative CSR and contribute to development in general and land reform in particular optimally.

REFERENCES

African Institute of Corporate Citizenship (AICC) (2005). Why we need to link BEE to CSR. Business Day, Jan./Feb.

Carroll AB (2008). A history of corporate social responsibility: Concepts and practices. In: Crane A, McWilliams A, Matten D, Moon J, Siegel DS (eds). The Oxford handbook of corporate social responsibility. Oxford: Oxford University Press, pp. 19-46.

Constitution of the Republic of South Africa (1996). Constitution of the Republic of South Africa as adopted by the Constitutional Assembly on 8 May 1996 and as amended on 11 October 1996. (ISBN: 0-260-20716-7.)

Crowter D, Aras G (2008). Corporate social responsibility. London: Ventus.

Cutlip SM, Center AH, Broom GM (1985). Effective public relations, 6th ed. London: Prentice-Hall. PMCid:PMC1236118

De Bakker FGA, Groenewegen P, Den Hond F (2005). A bibliometric analysis of thirty years of research and theory on corporate social responsibility and corporate social performance. Bus. Soc. Rev. 44(3):283–317. http://dx.doi.org/10.1177/0007650305278086

De Villiers B (2008). Land reform: A commentary. Policy paper 4. Dunkeld: Konrad-Adenauer-Stiftung.

Du Toit J (2009a). Land reform success stories from the agricultural family in the Free State: The role of agribusiness. (Presentation delivered at Nampo Park on 10 June 2009). Bothaville. (Unpublished.)

Du Toit J (2009b). Verbal communication with the author. Klerksdorp. (Notes in possession of the author.)

European Union Commission (2002). Corporate social responsibility. http://www.eubusiness.com/social/corporate-social-responsibility-in-the-eu/ Date of access: 5 June 2009. IOD see Institute Of Directors

Institute of Directors (2002). Executive summary of the King report 2002. http://www.corporatecompliance.org/international/SouthAfrica/KingCommitteeCorporateGovernanceExecutiveSummary2002.pdf. Date of access: 6 Aug. 2008.

Institute of Directors (2009). King report on governance for South Africa. Parklands: IOD. ISO International Organization for Standardization.

International Organization for Standardization (2010). ISO 26 000: Guidance on social responsibility. Geneva: ISO.

Lahiff E (2008). Land reform in South Africa: A status report 2008. Research report 38. Cape Town: Programme for Land and Agrarian Studies, University of the Western Cape. PMid:18271783

Lantos GP (2001). The boundaries of strategic corporate social responsibility. J. Consum. Mark. 18(7):595–630. http://dx.doi.org/10.1108/07363760110410281

Miller C, Pope A (2000). Land title in South Africa. Cape Town: Juta. Legislation, South Africa.

Schwartz MS, Carroll AB (2003). Corporate social responsibility: A three-domain approach. Bus. Ethics Quart. 13(4):503–530. http://dx.doi.org/10.5840/beq200313435

Senwes (2008). Annual report. http://www.senwes.co.za/REUSE/go/download.asp?download=/eng/Corporate/FinResults/SenwesAnnual_2008_ENG.pdf. Date of access: 8 Aug. 2009.

Senwes (2011). Annual Report. http://www.senwes.co.za/Files/main_corporate/annual_reports/2011/Senwes_Annual_Report_2011.zip. Date of access: 17 Jan. 2012.

Senwes (2012a). Senwes corporate vision and profile. http://www.senwes.co.za/Korporatief/Korporatiewe_Visie_en_Profiel.aspx?sflang=en-ZA. Date of access: 17 Jan. 2012.

Senwes (2012b). Black economic empowerment. http://www.senwes.co.za/Korporatief/Swart_Ekonomiese_Bemagtiging/SEB_beleid.aspx?sflang=en-ZA. Date of access: 17 Jan. 2012.

South Africa (1994). Restitution of Land Rights Act 22 of 1994. Pretoria: Government Printer.

South Africa (2003). Broad-based Black Economic Empowerment Act 53 of 2003. Pretoria: Government Printer.

Department of Trade and Industry, South Africa (2005). Notice of the draft 2nd phase of the codes of good practice on broad-based black economic empowerment. (Proclamation No. R. 2036, 2005.) Government Gazette, 28351, 20 Dec.

Department of Trade and Industry, South Africa (2008). Broad-based black economic empowerment: transformation charter for agriculture (AgriBEE). (Proclamation No. R. 314, 2008.) Government Gazette, 30886. 20 Mar.

South African Grantmakers' Association (SAGA) (2002). The King report 2002: Implications for corporate social investment in South Africa. SAGA Briefings (1) November 2002.

Trialogue (2005). The CSI handbook, 8th ed. Cape Town: Trialogue.

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