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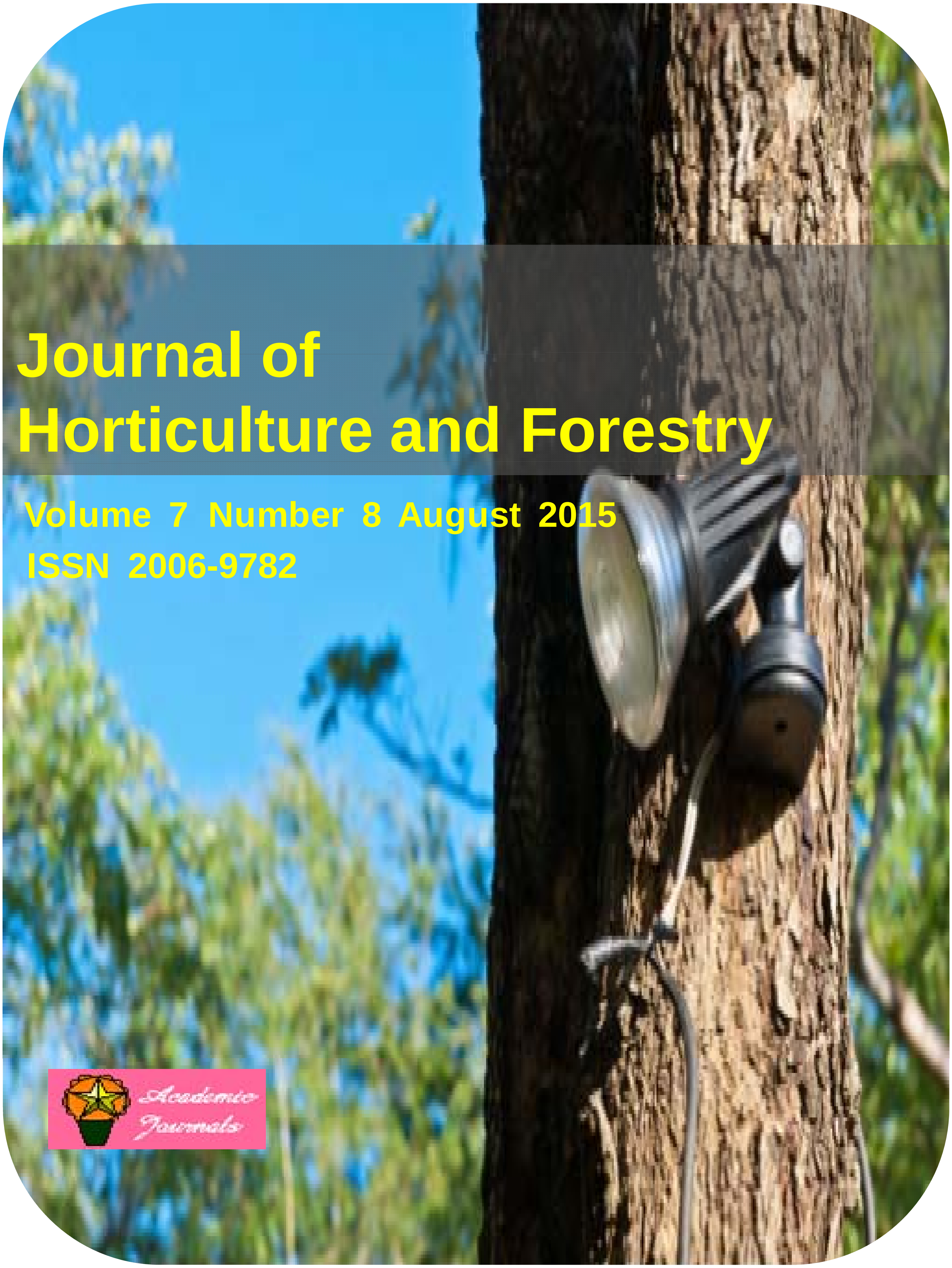

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Full Length Research Paper

Nutrient status of potato (*Solanum tuberosum* L.) tubers and lettuce (*Lactuca sativa* L.) leaves produced along the bank of River Beressa

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The discharge of untreated solid and liquid wastes containing toxic heavy metals (Cr, Pd, Ni, Hg and As) from municipal and industrial activities has deteriorate the potential of Beressa River water mainly for irrigation purpose and affect the chemical property of soils and vegetables grown along the bank. Thus, this work was conducted to assess the concentrations of both essential nutrients (Ca, Mg, K, P, N, Mn, Fe, Cu and Zn) and heavy metals (Cd, Cr, Pd, Ni, Hg and As) in potato tubers and lettuce leaves produced along the bank of river using irrigation. Depending on their position and extent of water pollution, three different farms were identified and representative plant samples were collected from each farm for laboratory analysis. The vegetables from the non-irrigated farm were characterized by their lower contents of Ca, Mg, K, P, N, Mn, Fe, Zn and Cu. There was no detection of heavy metals in the potato tubers collected from farms 1 and 2, and except Cd, the lettuces of farm 3 had the highest concentration of toxic heavy metals. Apart from the lettuce leaves harvested from the irrigated farms, all the vegetables were safe for consumption and had a good essential nutrient content than the non-irrigated farm. Eventually, it is important to protect and mitigate the quality of the environment through creating awareness and conducting different studies of natural resources pollution remediation and controlling.

Key words: Potato, lettuce, nutrients, heavy metals, water pollution, Beressa River.

INTRODUCTION

Most developmental activities have a desirable role in developing countries like Ethiopia as they seen from the perspective of socioeconomic advancements. However, a wrong implementation and poor management of urbanization and industrialization activities deplete the natural resources (Jande, 2005), produce large amounts

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of toxic wastes that deteriorate the quality of the ecosystem (Fisseha et al., 2008) and cause ill health on human, aquatic life and other living things (Ashraf et al., 2010) and cause loss of crop productivity (Gbehe, 2004). For instance, Cadmium has adverse effects on the kidneys and bones. Even up on a long-term consumption it replaces Zn in the body and leads to body disorders. Arsenic is known to be carcinogenic and toxic but there is little direct evidence of toxicity related to the ingestion of nickel. Lead can cause a variety of neurological disorders. In children, it inhibits brain cell development and prevents the uptake of iron. So people ingesting lead often exhibit symptoms of anemia including pale skin, fatigue, irritability and headaches. (http://www.lenntech.com/processes/heavy/heavy-metals/heavymetals.htm#ixzz1torQPuv7).

Utilization of water consisting industrial effluents, agricultural discharges and household sewages affect the quality of soils and vegetations by introducing toxic heavy metals (Carter, 1985; Morera et al., 2001; Bridge, 2004). For instance, excessive entrance of inorganic pollutants into the soil system reduce its fertility status and natural filtering/ buffering capacity (Blum, 1996), influence activity and abundance of most soil microbes (Gasper et al., 2005) and deteriorate the quality of plants by affecting their growth and metabolism (Baccouch et al., 1998), photosynthesis, respiration, stomata functioning and biomass production (Larcher, 1984; Pierzeynski and Schwab, 1993).

According to Bigdell and Seilsepour (2008), the quality the Firoozabad River in Shahre Rey, Iran was deteriorated by the emissions from tannery, painting factory, soap factory, melting industry and wastes from domestic uses, garages, gas stations and hospitals which fortunately pollute the soils under irrigation and the produced vegetables with Cd, Pb, Cu and Zn. The Ona River in Ibadan, Nigeria deposited most of industrial wastes on farms of its flood plain and increased the level of N, P and K in the soils which inhibited the toxic absorption of Pb. Cu, Zn, Cr, Fe and Cd by arable crops like maize and vegetables (Ande, 2014).

Among the streams and rivers of Ethiopia, the Beressa River is the one that receives major portion of untreated solid and liquid wastes released from municipal and industrial activities in the town of Debre Berhan (Tebasie) (Negash et al., 2011). This situation has deteriorated of the water quality for irrigation and other domestic uses because of raised levels of chemical oxygen demand (COD), biochemical oxygen demand (BOD), PO_4^{3-}, total suspended solids (TSS), total dissolved solids (TDS), Pb and Hg (Awgchew et al., 2015). According to Negash et al. (2011) and Haymanot (2014), the soils being irrigated from the river have a slightly acidic pH and considerable amount of toxic heavy metals like Co, Cr, Ni, As, Hg, Pb and Cd. Thus, this study was proposed and conducted in order to assess the concentrations of essential nutrients and heavy metals in the potato tubers and lettuce leaves produced using irrigation from the Beressa River water.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Tebasie sub-town of Debre Berhan town which is located at 09° 35' 45'' to 09° 36' 45'' north latitude and from 39° 29' 40'' to 39° 31' 30'' east longitude and found at 125 km north east of Addis Ababa with an elevation ranging between 2800 and 2845 m above sea level. The soil is vertisol type with clay loam texture and slightly acidic characteristics. Moreover, it is vulnerable to erosion and degradation due to overgrazing, poor conservation practice, deforestation and unwise utilization of natural resources. The twenty seven years (1985-2011) data obtained from the Ethiopian National Meteorological Agency indicates that, the area receives a mean annual rainfall of 927.10 mm and characterized by a unimodal rainfall pattern with a maximum (293.02 mm) and minimum (4.72 mm) peaks in August and December, respectively. The mean monthly maximum and minimum temperature range from 18.3 to 21.8°C and from 2.4 to 8.9°C, respectively (Figure 1).

Site selection, sample collection and preparation

In this study, three farms (Farm 1 – Eyerusalem Vegetable Farm; Farm 2 - Debre Berhan University's Research and Demonstration Field; Farm 3 - Tera Vegetable Farm) were selected based on their position and exposure to pollution.

Farm 1 and 3 (Figure 2), located at the upper and down streams of the River on its way through the Tebasie sub-town, were irrigated by the river water during dry season for commercial vegetable crop production; whereas, farm 2 was only irrigated with rainwater and never been irrigated by the river water.

Representative plant tissue samples were collected from each farms by considering the slope gradient (bottom, medium and upper) and agronomic management practices in a zigzag pattern with an interval of five steps and from each experimental plants, undamaged and matured edible parts were collected. A fully grown lettuce leaf samples were taken in the last week of March 2013 from the middle part by discarding the old leaves at the bottom and young rolled leaves at the top part. While, the potato tuber samples were taken in the early week of June 2013 from each plant with a medium/seeding size.

The lettuce leaf samples were cleaned by washing several times with water and 0.2 % detergent solution to remove the dusts and waxy coating, respectively, with no rubbing, and then washed by a 0.1 M HCl and plenty of distilled water. Before soaking the samples with tissue paper, they were washed with double distilled water to carry out micronutrient analysis (FAO, 2008). Moreover, the potato tubers were harvested and washed by water to remove adhering soil and then were cleaned and treated like the lettuce and sliced using a slicer. The tuber and leaf samples were air dried on a clean plastic tray at a room temperature for a week in a dust free atmosphere and oven dried at 60°C for 48 h before being ground in an electric stainless steel mill (the cup and blades were cleaned before each sample) and sieved through a 0.5 mm sieve and stored in glass desiccators until analysis time (Ryan et al., 2001).

Laboratory analysis

The plant sample were wet-digested by a 2:1 ratio of nitric (HNO_3) and perchloric acid ($HClO_4$) and analyzed for the total nitrogen and phosphorus contents by the Kjeldahl and gravimetric ammonium phosphomolybdate method, respectively and the total contents of

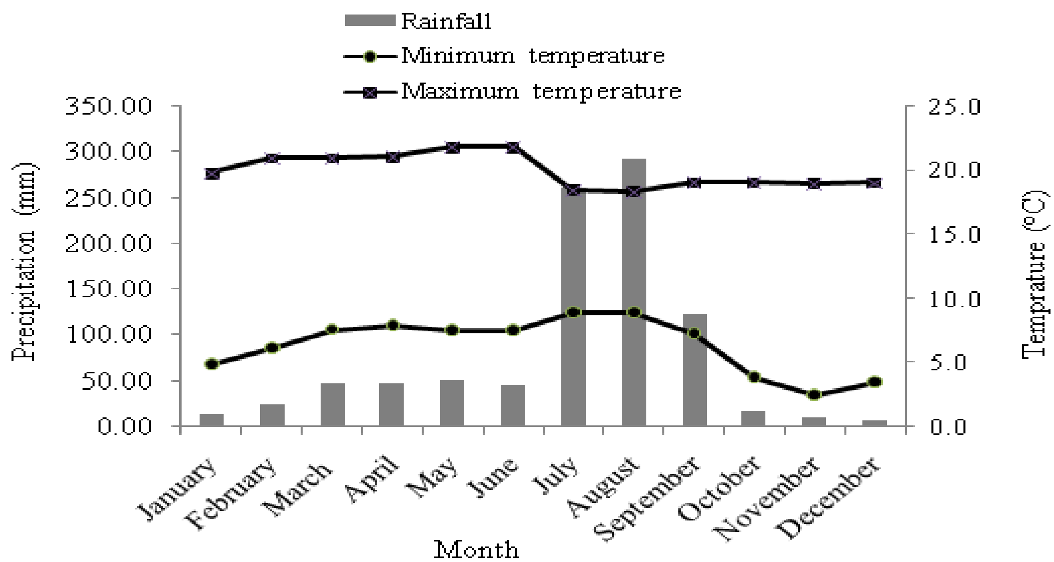

Figure 1. Mean monthly rainfall and minimum and maximum temperatures of the study area.

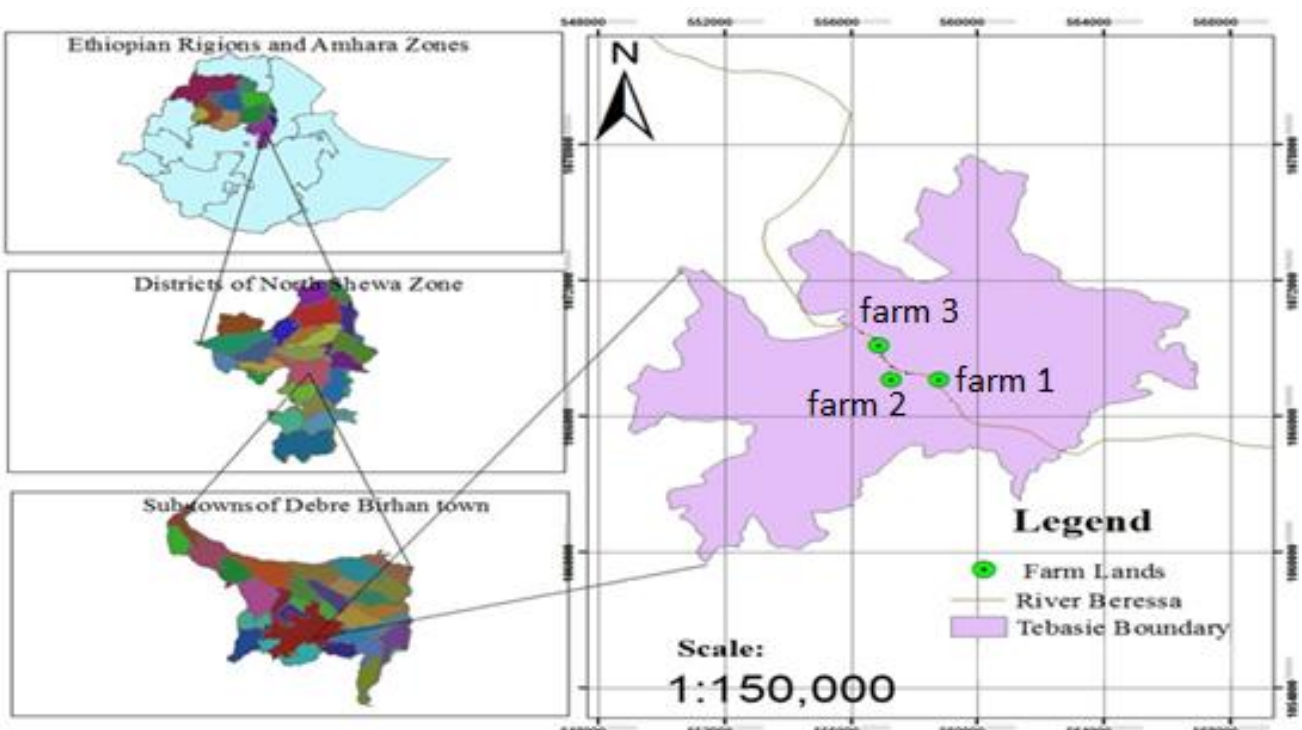

Figure 2. Location map of the study area.

K, Ca, Mg, Fe, Zn, Mn, Cu, Cd, Cr, Pb, As, Ni and Hg were determined by flame atomic absorption spectrophotometer (AAS) (Ryan et al., 2001; FAO, 2008).

RESULTS AND DISCUSSION

The mean essential nutrients and heavy metals composition of potato tuber and lettuce leaf samples collected from three different farms found in Debre Berhan (Tebasie sub town), Ethiopia is presented in Table 1.

The amounts of Ca were 128.3, 120.24 and 141.35 mg kg^{-1} in the potato tubers and 4200, 2042 and 3685 mg kg^{-1} in the lettuce leaves of farms 1, 2 and 3, respectively (Figure 2). The vegetables produced from farm 2 had the lowest content (Table 1) which could imply something to

Table 1. The mean essential nutrients and heavy metals composition in the potato tuber and lettuce leaf tissues.

Content (mg kg^{-1})	Potato tuber			Lettuce leaf		
	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3
Calcium	128.3	120.24	141.35	4200.0	2042.0	3685.0
Magnesium	350.0	292.0	900.0	1675.0	806.0	1500.0
Potassium	20500	8071	17000	52500	20100	61500
Phosphorus	606.0	393.0	547.0	4825.0	2969.0	3688.0
Nitrogen	7200	6700	8100	36300	31800	34900
Manganese	13.0	19.35	34.75	190.25	105.35	122.25
Iron	258.0	214.45	286.75	919.5	487.5	463.75
Copper	3.15	2.02	2.70	9.55	3.15	3.80
Zinc	19.1	34.7	74.4	50.45	30.3	37.1
Cadmium	ND	ND	ND	ND	ND	ND
Chromium	ND	ND	0.01	0.03	ND	0.05
Lead	ND	ND	ND	0.02	ND	0.06
Nickel	ND	ND	0.01	ND	ND	0.05
Arsenic	ND	ND	0.02	0.04	ND	0.07
Mercury	ND	ND	0.01	ND	ND	0.02

ND = Not detected.

suspect the River water. However, the concentrations of Ca in the harvested vegetables were below and in the permissible ranges of safe consumption, 1000 to 10000 mg kg^{-1} (FAO, 2008); because its level in the river water was below the maximum permissible limit (Awgchew et al, 2015) and all the soils had no problem of calcium deficiency (Haymanot, 2014).

The lowest contents of Mg were detected in the potato tubers (292.24 mg kg^{-1}) and lettuce leaves (806.0 mg kg^{-1}) of farm 2 while the maximum was in the potato tubers (900 mg kg^{-1}) of farm 3 and lettuce leaves (1675 mg kg^{-1}) of farm 1 (Table 1). From these findings, the river might condemn for the concentrations in the vegetables of the irrigated farms due to a raised presence of Mg in the water (Awgchew et al., 2015) and concerned soils (Haymanot, 2014). Nevertheless, all the potato tubers were below the minimum permissible limit and except the lettuce leaves of farm 2 (Figure 2), all were in the acceptable range (1000 to 4000 mg kg^{-1}) for safe consumption (FAO, 2008).

The potato tubers and lettuce leaves harvested from the non-irrigated farm (farm 2) had the lowest (8071 and 20100 mg kg^{-1}, respectively) content of K (Table 1) which strengthen the suspicion on the River for its concern. Because, in the river water there was a higher K concentration (Awgchew et al., 2015) and even though all farms had no deficiency of K, the irrigated farms were superior in their K content (Haymanot, 2014). According to FAO (2008), except the potato tubers of farm 2, all were in the permissible range of 10000 to 50000 mg kg^{-1} for safe consumption but the lettuce leaves of the irrigated lands, farms 1 and 3 (Figure 2) were out of the range for safe consumption.

The lowest contents of P were recorded in the potato tubers (393 mg kg^{-1}) and lettuce leaves (2969 mg kg^{-1}) of farm 2 (Table 1). The detected concentrations in the vegetables could imply the presence of some relation between the River water and the soils under irrigation; because phosphate was the one among the pollutants in the Beressa River (Negash et al., 2011; Awgchew et al., 2015) and the two irrigated farms had higher P values than the non-irrigated (Haymanot, 2014). However, the contents in the potato tubers of all farms were below the minimum permissible limit whereas all the lettuce leaves were in the permissible range, 2000 to 5000 mg kg^{-1}, of safe consumption (FAO, 2008).

The concentrations of total nitrogen (TN) in the potato tubers were 7200, 6700 and 8100 mg kg^{-1} and in the lettuce leaves were 36300, 31800 and 34900 mg Kg^{-1} at farms 1, 2 and 3, respectively (Table 1). Despite the differences in fertilization and other farm management practices, the River could blamed for the elevated TN concentrations in the vegetables of farms 1 and 3 (Figure 2) due to the detection of considerable amounts of ammonia and nitrate in the water near the two farms that might have a direct connection with the relative higher amounts of TN in the concerned soils (Awgchew et al., 2015; Haymanot, 2014). According to FAO (2008), the concentrations in all lettuce leaves were in the acceptable range (20000 to 50000 mg kg^{-1}) of safe consumption but the potato tubers were found below the minimum permissible limit.

The amounts of Mn were 13.0, 19.35 and 34.75 mg kg^{-1} in the potato tubers and 190.25, 105.35 and 122.25 mg kg^{-1} in the lettuce leaves collected from farms 1, 2 and 3, respectively (Table 1). Moreover, the contents of Fe in the potato tubers were 258, 214.45 and 286.75 mg kg^{-1} while 919.25, 487.5 and 463.75 mg kg^{-1} in the lettuce leaves of farms 1, 2 and 3, respectively (Table 1). The River water might not blamed as a cause for the contents in the vegetables of the irrigated farms; because the highest amounts of Fe and Mn were found in the soil of non-irrigated farm (Haymanot, 2014) and there was no detection of these elements in the river water sampled near the two irrigated farms (Awgchew et al., 2015). According to FAO (2008), only the potato tubers of farm 3 and lettuce leaves of all farms were in the permissible range of Mn (20-300 mg kg^{-1}) for safe consumption but only the Fe content in the potato tubers of farm 2 (Figure 2) was in the permissible range (50 to 250 mg kg^{-1}) of safe consumption.

The amounts of Cu in the potato tubers were 3.15, 2.02 and 2.7 mg kg^{-1} while 9.55, 3.15 and 3.8 mg kg^{-1} in the lettuce of farms 1, 2 and 3, respectively (Table 1). The River had a direct relation with the amounts in the vegetables; because the contents in soils the irrigated farms (Figure 2) were higher than the non-irrigated (Haymanot, 2014) and there was a significant detection of Cu in the River water near the two irrigated farms (Awgchew et al., 2015). However, except the lettuce leaves harvested from farm 1, all the vegetables were below the minimum permissible limit (5-20 mg kg^{-1}) of safe consumption (FAO, 2008).

The contents of Zn in the potato tubers and lettuce leaves ranged from 19.1 to 74.4 mg kg^{-1} and from 30.3 to 50.45 mg kg^{-1}, respectively (Table 1). The highest presence of zinc in the River was recorded at water sampling site near farm 3 (Awgchew et al., 2015), and according to Haymanot (2014), the content of Zn in the soils of farm 3, 1 and 2 (Figure 2) was ranked in the order of decrease. Thus, the concentrations in each of the vegetables had no concern with the River water and the irrigated soils. Because, the potatoes harvested from the non-irrigated farm (farm 2) had the highest content than that of farm 1 and the lettuce leaves of farm 1 had the lowest content than farm 3. Except the potato tubers of farm 1, all the harvested vegetables were in the permissible range (20 to 100 mg kg^{-1}) of safe consumption (FAO, 2008).

Cadmium was not detected in the harvested vegetables of all farms (Table 1) and the River water might not be blamed by any means; because Cd was not detected in the River water at the sites around farms 1 and 3 (Figure 2) and in the soils of the irrigated and non-irrigated farms (Awgchew et al., 2015; Haymanot, 2014). Additionally, Cr was not detected in the potato tubers of farms 1 and 2, and in the lettuce leaves of farm 2 but it was 0.01 mg Kg^{-1} in the potato tubers of farm 3 and 0.03 and 0.05 mg kg^{-1} in the lettuce leaves of farms 1 and 3, respectively (Table 1). In this case, the River water might be a reason for the presences of Cr; because relatively there was a higher concentration in the soils of the irrigated farms than the non-irrigated and also there was a considerable amount in the River water around the two irrigated farms that have been expressed in the River water and vegetables in accordance (Awgchew et al., 2015; Haymanot, 2014; Negash et al., 2011). According to FAO (1991), the detected amounts of Cr were below the maximum permissible limit (0.1 mg kg^{-1}) for safe consumption.

The potato tubers harvested from all farms and the lettuce leaves from the non-irrigated farm had no Pb but there were 0.02 and 0.06 mg kg^{-1} in the lettuce leaves of farms 1 and 3, respectively (Table 1) which were below the maximum permissible limit of 0.3 mg kg^{-1} (FAO, 1991) for safe consumption. The River water might be an indirect source of lead in the lettuce leaves of the irrigated lands, farms 1 and 3 (Figure 2); because the contents in the River water at the sites around the irrigated farms were above the maximum permissible limit and were about six times below the maximum permissible limit in the soil of the concerned farms (Awgchew et al., 2015; Haymanot, 2014; Negash et al., 2011).

Nickel was detected only in the potato tubers (0.01 mg kg^{-1}) and lettuce leaves (0.05 mg kg^{-1}) of farm 3 (Table 1) found below the maximum permissible limit of 0.5 mg kg^{-1} (FAO, 1991) for safe consumption. Even though the concentration in the River water was below the maximum permissible limit, there was relatively a higher content of Ni in the soils of farm 3 and in the water at the site near farm 3 and also it was not detected in the soils of farms 1 and 2 (Awgchew et al., 2015; Haymanot, 2014; Negash et al., 2011). Thus, the River water might be a factor for the presences in the vegetables of farm 3 (Figure 2).

There was no As in the potato tubers of farm 1 and 2 and lettuce leaves of farm 2. However, it was 0.02 mg kg^{-1} in the potato tubers of farm 3 and 0.04 and 0.07 mg kg^{-1} in the lettuce of farms 1 and 3, respectively (Table 1). There was no doubt in considering the River as a reason for the detected amount of As in the soils and vegetables of the irrigated farms of 1 and 3 (Figure 2). Because, there was a significant amount of As in the River water (Awgchew et al., 2015; Negash et al., 2011) and relatively higher amount in the soils of the two irrigated farms (Haymanot, 2014). According to FAO (1991), the detected amounts were below the maximum permissible limit (0.2 mg kg^{-1}) for safe consumption.

There was no Hg in the vegetables of farms 1 and 2, but there was in the potato tubers (0.01 mg kg^{-1}) and lettuce leaves (0.02 mg kg^{-1}) of farm 3 (Table 1) which was found below the maximum permissible limit of 0.05 mg kg^{-1} (Bergmann, 1993) for safe consumption. Specifically, it was possible to say that the River was a main cause for the presence of Hg in vegetables of farm 3 (Figure 2). Because, the highest amount of Hg was detected in the water samples collected from the sites near farm 3 and in the soils of this farm (Awgchew et al., 2015; Haymanot, 2014).

SUMMARY AND CONCLUSIONS

The vegetables (potatoes and lettuces) harvested from the non-irrigated farm (farm 2) were the least in their Ca, Mg, K, P and N contents. The highest concentrations of Mn and Fe were recorded in the potato tubers of farm 3 and lettuce leaves of farm 1. The amounts of Cu in the vegetables of farm 1 and the concentrations of Zn in the potato tubers of farm 3 and lettuce leaves of farm 1 were found maximum. According to Mohammed et al. (2014), irrigating the farmlands in selected areas of Vidyaranyapuram, Mysore city of India, with sewage water containing a permissible levels of total N, total P, potassium and heavy metals as proposed by FAO, led to the decrease of soil pH and significant increase of N, P, K, Ca, Mg, Na, Fe, Mn, Cu, Zn and Pb contents in the soils and crops. There was no detection of heavy metals in the potato tubers collected from farms 1 and 2 (Figure 2). The toxic heavy metals like Cd and Pb were not found in the lettuce leaves of farm 2 and in the potato of farm 3. The lettuce leaves of farm 1 were free from Cd, Ni and Hg. Moreover, excluding Cd, the lettuces of farm 3 had highest concentration of the toxic heavy metals. The level of heavy metals (As, Cd, Co, Cu, Fe, Ni, Pb and Zn) in the soils and produced plants of the different farmlands located near waste dumping sites of Lafia, Nigeria was higher, but found below the lower permissible limit of the WHO (Opaluwa et al*.,* 2012).

In conclusion, except the lettuce leaves harvested from the irrigated farms (which was due to its excessive K content), all vegetables were safe for consumption and the vegetables harvested from the irrigated farms (farm 1 and 3) had a good essential nutrient content than the non-irrigated farm. In addition, the lettuce leaves of farm 3 have required extra attentions for frequent uses. However, in the future it is exceedingly important to protect and mitigate the quality of the environment through creating awareness and conducting different studies of natural resources pollution remediation and controlling.

Conflict of Interest

The authors have not declared any conflict of interest.

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Effect of climatic conditions on flowering and fruiting of *Tamarindus indica* (Fabaceae)

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This study examined effects of climatic conditions on patterns of flowering and fruiting of tamarind (*Tamarindus indica* L.). Data were recorded over a period of 26 months in two contrasting climatic zones. The monitoring revealed that irrespective of climatic zones, flowering starts by the end of the dry season when hygrometry begins to rise and lasts two to three months. Fruiting begins around the peak of the rainy season and reaches the ripening stage six to eight months later during the dry season. Flowering and fruiting abilities weakly varied with climatic conditions. Flowering durations and active phases seemed to be significantly longer (p < 0.001) under wetter climatic conditions (Sudan-Guinea zone) while fruiting parameters showed the opposite trend. Flowering length was found to be weakly correlated to climatic conditions while the latter variable was positively correlated to fruiting length. A negative correlation was observed between fruiting length and trees diameter; suggesting that the younger the tree, the longer the fruiting phase. These results provide insights into the patterns of phenological events of tamarind that could help in managing its populations and anticipating its flowering and fruiting shifting response to climate changes. Thorough research should however focus on modeling the combined effect of climate, soil, land use regimes and age of trees on the inter-annual variation of flowering and fruiting patterns and productivity.

Key words: Indigenous fruit trees, phenology, climate, Benin, West Africa.

INTRODUCTION

Non-timber forest products play a key role in the livelihoods of many rural communities and may be used as mean to ensure conservation of natural ecosystems (Marshall and Newton, 2003). Indigenous fruit trees such

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Table 1. Characteristics of the two climatic zones (climate data source:the local climatology and weather forecast institute, ASCENA).

Parameter	Sudan zone	Sudan-Guinea zone
Location	9°45'-12°25' N	7°30'-9°45' N
Rainfall regime	Unimodal	Unimodal
Rainfall (mm)	<1000	900-1110
Temperature (°C)	24-31	25-29
Relative humidity (%)	18-99	31-98
Soil	Hydromorphic soils well drained and lithosols	Ferruginous with variable fertility
Climate type	Tropical	Tropical

as *Tamarindus indica* L. (Fabaceae), tamarinier (French), tamarind (English) or *Djêtami / N'djabé* (Fulfuldé: Fulani language) are daily used in rural households as food or medicine, and provide cash income to rural women (Fandohan et al., 2010a). It has been recently identified as one of the major agroforestry tree species to be prioritized for future crop in sub-Saharan Africa (Akinnifesi et al., 2008). For the above-mentioned goal to be realistic, thorough studies on ecological range, traditional importance, reproductive processes, phenological patterns, fruiting potential and genetic diversity at large scales (that is, countries and regions) are required. There have been extensive studies on biochemical, medicinal and nutritional properties, reproductive biology, morphology, cultivation and genetics of tamarind (El-Siddig et al., 2006). According to the latter authors, tamarind has a promising potential for domestication and may play a key role in strategies seeking to reduce poverty and malnutrition, especially in the developing world. Although the distribution range of tamarind in Africa evidences its plasticity under the tropics (Bowe and Haq, 2010), recent work has reported its populations to be sensitive to drought in its native areas (Diallo, 2001; Fandohan et al., 2010b). This study aims to provide some insights into the patterns of its phenology across a climatic gradient.

The growing number of studies on woody plants phenology has yielded various findings. It has been shown that patterns of phenological events in some species (e.g. *Combretum aculeatum* Vent. and *Acacia adansonii* (Guill & Perr) O.Ktze) greatly fluctuate with years whereas in some others (e.g. *Guiera senegalensis* GF.Gmel., *Ziziphus mauritiana* Lam.) are independent of the variation in climatic factors (Grouzis, 1991). Studies demonstrate that the patterns of phenological events of woody plants in warm climates are tightly linked with air hygrometry (Piot et al., 1980; Okullo et al., 2004), soil moisture (De Bie et al., 1998) and topography (Law et al., 2000).

Interest in the phenology of tamarind tree has risen during the second half of the last century. Recent works provided noticeable information on leafing strategy of this species, proportion of flowers and fruits loss and degree of synchronism of flowering and fruiting at individual and population levels. Tamarind is a semi-evergreen species showing leaf shedding and sprouting once a year, during a short period (one-two weeks) just before the rainy season, displaying scleromorphic features as adaptation to drought (De Bie et al., 1998). Flowering in this species is asynchronous at individual level but it is synchronous at population level (Diallo, 2001).

Nonetheless, at present, little is known about how climatic conditions alter its flowering and fruiting phenologies. Ignoring variations in climatic conditions and how they affect phenology may lead to erroneous generalizations of timing of phenological events and even misestimating variations in fruit production at inter-annual and inter-ecological range (De Bie et al., 1998; Assogbadjo et al., 2005).

This study aimed at assessing the extent to which flowering and fruiting abilities in tamarind vary with climatic conditions, and how the latter alters the period of active flowering and fruiting active phases.

MATERIALS AND METHODS

Study area

This study was conducted in two climatic zones of Benin (West Africa) hosting natural populations of *Tamarindus indica*: The Sudan zone and the Sudan-Guinea transition zone. Table 1 summarises location and characteristics of the two climatic zones.

Data collection

Due to resource limitation, a total of forty four trees (20 in the Sudan-Guinea zone and 24 in the Sudan zone) with $D_{1.30}$ ≥10 cm were randomly selected for flowering and fruiting monitoring. To facilitate data collection, trees were sample depending on accessibility of their location. It was not possible for a single person to be collecting the data at every location at the same time. Thus, data were collected synchronically by the main author aided by well trained field technicians residing in each zone.

Flowering and fruiting of all sampled individuals were monitored for a two-year period (February 2008 to January, 2010). Flowering and fruiting abilities were considered as two categorical variables with two possible values. Each sampled individual was attributed the value 1 if flowering, otherwise 0, and again 1 if fruiting, otherwise, 0. Four stages of flowering and four stages of fruiting were distinguished and respectively coded from 1 to 4 following

Table 2. Phenological events.

	Phenophase stages			
	1	2	3	4
Flowering	*Start of flowering*: appearance of the first buds of flowers	*Flowering*: first flower buds are opening whereas others are appearing	*Full flowering*: most of flowers are opened	*End of flowering*: no more new flowers appear
Fruiting	*Start of fruiting*: first developing fruits	*Fruiting is going on*: presence of first full size green fruits	*Fruiting*: presence of fully developed brown fruit	*Peak of fruiting*: most of fruits are ripened

Table 3. Effect of climatic conditions and years on flowering and fruiting ability of tamarind: results of the GLM with binomial error distribution.

Factors	Flowering ability					Fruiting ability				
	Df	Dev	Resid. Df	Resid. Dev	Pr(>Chi)	Df	Dev	Resid. Df	Resid. Dev	Pr(>Chi)
Zone	1	26.89	2	39.57	<0.001	1	14.47	2	31.50	<0.001
Years	1	32.25	1	7.32	<0.001	1	19.60	1	11.90	<0.001

Df, degree of freedom; Resid, residual; Dev., deviance.

Okullo et al. (2004) and Kelly et al. (2007) as described in Table 2. Four variables were defined from the stages described in Table 2; (i) length of flowering and length of fruiting respectively include the period (expressed in days) between the stages 1 and 4, and (ii) length of active phase of flowering and length of active phase of fruiting respectively include the period (expressed in days) between the stages 2 and 3. During the data collection phase, information on fruit harvesting techniques was also recorded. Finally, climatic condition was also considered as a categorical variable with two possible values: 0 if Sudan zone and 1 if Sudan-Guinea zone.

Data analysis

Effects of climatic conditions and year on flowering and fruiting abilities (in term of whether a tree flowers or fructifies in a given year) were assessed using a generalized linear model (GLM) based on binomial error distribution while effects of climatic conditions on the length of flowering and fruiting and lengths of active phases of flowering and fruiting were analyzed using the GLM based on either Poison or Negative binomial error distribution in R software (R Core Team, 2015). The negative binomial error distribution was used to overcome the over dispersion which was not corrected by the quasi poisson error distribution (Crawley, 2007). To test whether flowering and fruiting lengths and active phases correlate with trees $D_{1.30}$ the Pearson correlation coefficient was used in package Hmisc (Frank et al., 2014) of R software.

RESULTS

Effect of climatic conditions on flowering and fruiting abilities

Significant differences (p<0.001) were found in flowering and fruiting abilities between climatic zones and years (Table 3). Irrespective of climatic conditions, all sampled trees flowered during the first year (Figure 1a). Little differences were observed in fruiting ability among climatic conditions in the first year (Figure 1b). In the Sudan zone however, 5% of trees faced total immature fruit abortion whereas 12.5% did not fruit at all after the flowering phase. In the Sudan-Guinea zone, 25% of trees faced total fruit abortion (Figure 1b).

During the second year of the study, no important changes were observed in flowering and fruiting abilities of surveyed trees in the Sudan zone (Figure 1a and b); fructification failures were also noticed on the same individuals. In contrast, no tree flowered and thus did not bear fruits in the Sudan-Guinea zone (Figure 1a and b).

Figure 2 summarizes timing of phenological events in the two climatic zones. In the Sudan-Guinea zone, flowering started at the end of March and ended early in June while fruiting started in June and reached ripening peak in December in the first year (Figure 2a). In the Sudan zone, flowering started in April and ended in June while fruiting started in July and reached ripening peak between January and February in the first year (Figure 2b). In the second year, some changes were observed in the timing of these phenological events in the Sudan zone: Flowering started in May instead of April and fruiting started in October instead of August (Figure 2b). This implies delays of approximately 30 and 60 days, respectively (Figure 2b). In the second year in the Sudan-Guinea zone, surveyed tree did not flower and thus did not fructify (Figure 2a).

Effect of climatic conditions on flowering and fruiting lengths and active phases

The effect of climatic conditions on both flowering length

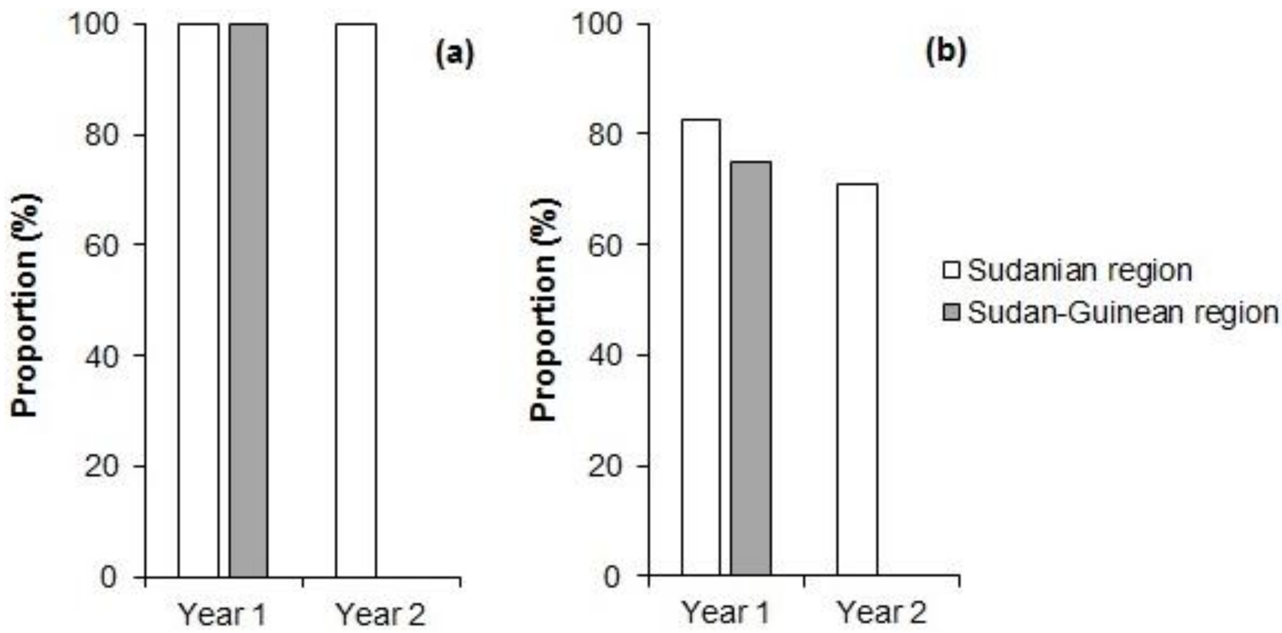

Figure 1. Proportion of tamarind trees flowering (a) and fruiting (b) across climatic zones and years of monitoring.

Table 4. Effects of climatic conditions on the length of flowering, fruiting and their active phases: results of the generalized linear model using either Poisson or negative binomial error distribution.

Responses	Df	Dev.	Resid. Df	Resid. Dev	Pr(>Chi)
Flowering length NB	1	9.74	42	43.92	0.002
Active flowering length PO	1	18.08	42	28.86	<0.001
Fruiting length NB	1	8.06	42	44.71	0.005
Active fruiting length NB	1	16.88	42	44.57	<0.001

NB, Negative binomial error distribution; PO, Poisson error distribution; Df, degree of freedom; Resid, residual; Dev., deviance.

and active phase was found to be significant ($p < 0.05$; Table 4). The mean durations for both total length and length of active phase of flowering were observed to be shorter in the Sudan-Guinea than in the Sudan zone (Figure 3a), respectively (56.00 ± 2.90 and 30.20 ± 0.25 days) and (70.92 ± 3.88 and 37.71 ± 1.33 days). Significant differences were also encountered for fruiting length and active phase ($p < 0.05$ and Table 4). Contrarily to flowering, both fruiting length and active phase duration were shorter in the drier Sudan than in the Sudan-Guinea zone (Figure 3b), respectively (166.75 ± 8.69 and 122.29 ± 5.83 days) and (196.30 ± 2.98 and 150.25 ± 2.32 days). In addition, the standard errors were relatively lower in the Sudan-Guinea zone than in the Sudan zone, suggesting little tree to tree variation within the former zone as compared to the latter one.

Length and active phase of flowering were weakly correlated with $D_{1.30}$ (Table 5). In contrast, a significant negative correlation was observed between total length fruiting and $D_{1.30}$ but not for length of active phase of fruiting (Table 5).

DISCUSSION

Results from this study indicate that climatic conditions have a significant impact on flowering and fruiting phenologies of *T. indica*. Under both climatic conditions, the beginning of flowering coincided with the end of the dry period whereas the active phase of the fructification took place during the rainy months. This suggests that the reproductive physiology of tamarind might be dependent on a climatic factor of which the variation is regular year-round. Such observations match with the hypothesis that phenological events' timing is linked with the variation in air hygrometry and rainfall. These observations are also consistent with Okullo et al. (2004) who noticed that there is a positive relationship between phenology timing and atmospheric relative humidity. On the other hand, the fruit ripening peak was reached

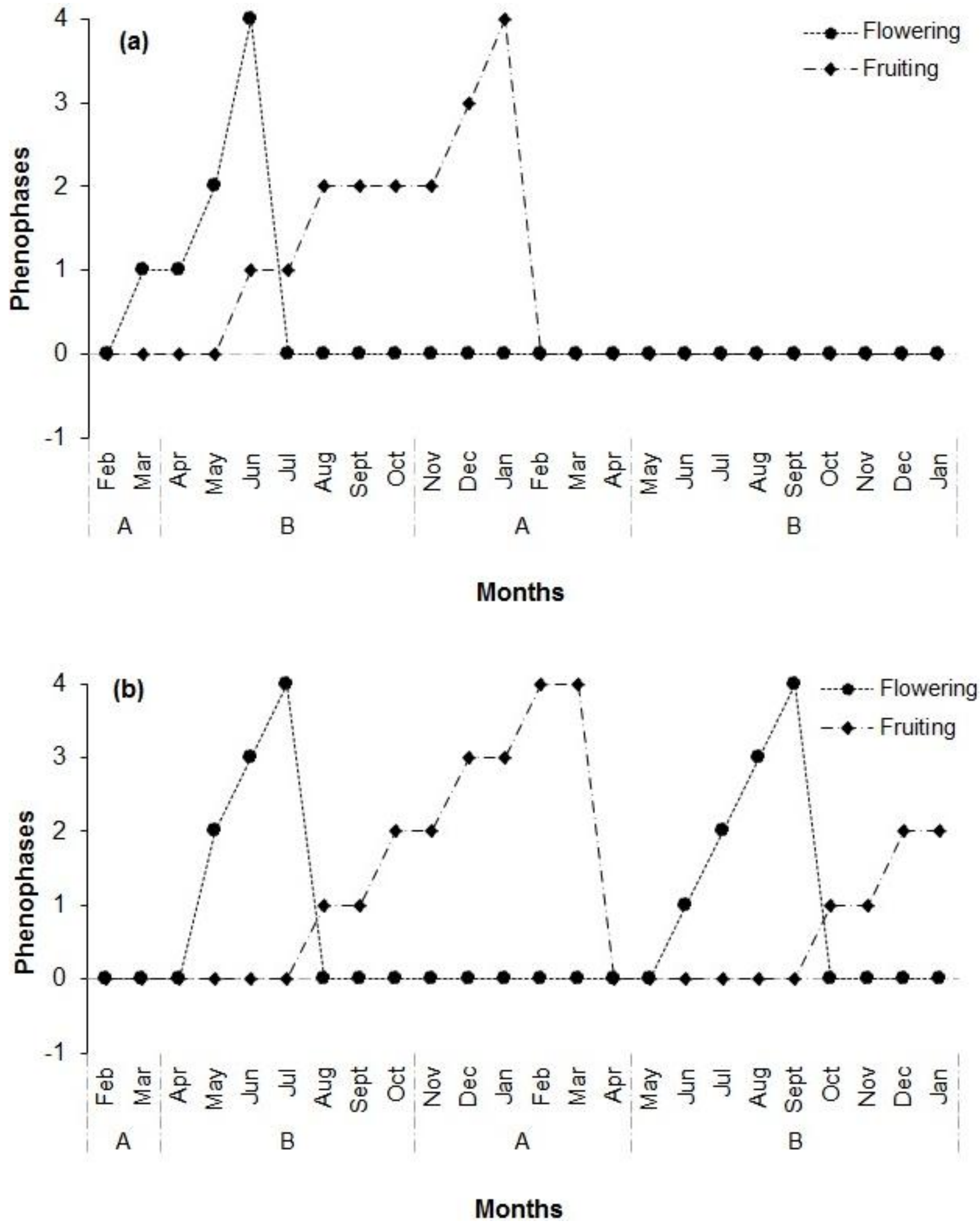

Figure 2. Temporal pattern of flowering and fruiting of *T. indica* in (a) the Sudan-Guinea zone and (b) the Sudan zone. A, dry season; B, rainy season.

during the dry seasons. It has been illustrated that hygrometry reduction is critical for tamarind fruit ripening (Morton, 1987).

For most investigated variables, the standard errors did not support synchronism of phenological events at population level. However, tree-to-tree variations were lower in the Sudan-Guinea zone, suggesting a tendency to phonological synchrony. According to Diallo (2001),

Table 5. Pearson correlations between $D_{1.30}$ and phonological parameters.

Phenological variables	$D_{1.30}$
Flowering length	$+0.12^{ns}$
Flowering active phase	$+0.17^{ns}$
Fruiting length	-0.51***
Fruiting active phase	-0.20^{ns}

Significance: ^{ns} p> 0.05; ***p< 0.001

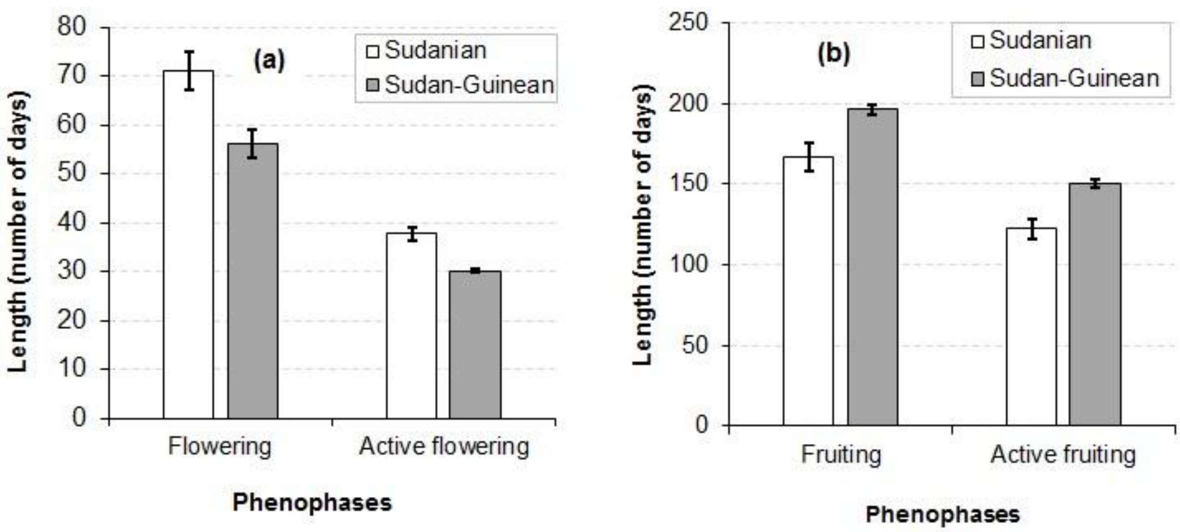

Figure 3. Variation of total length and length of active phases of flowering (a) and fruiting (b) in the studied zones. Errors bars represent the standard errors.

synchrony is an adaptation strategy developed against water scarcity in the Sahel and the Sudan zones. Flowering and fruiting activities may also intrinsically be timed to coincide with favourable weather conditions for optimizing performance (Khan, 1999). This may explain the observed inter-annual shifting in the timing of phenological events.

During the two years of observation, some trees showed either total flower abortion or overall immature fruit abortion after normal flowering. Fruit or flower abortions can be due to resource limitation (Stephenson, 1981). However, some individuals with very little differences in size and environmental conditions did not show such a problem (field observations). Abortion in tamarind can also be linked to sterility, poor floral visits by pollinators or high rate of self-pollination (Diallo et al., 2008). The same authors have pointed out that because flowering in tamarind at tree level is asynchronous, the absence of an effective pollinator (that can disseminate allo-pollen) at the right time of stigmatic receptivity will lead to a low rate of fecundated ovules and thus a poor reproduction. In addition, because one of the predominant pollinators of *T. indica* which is *Apis mellifera* L. mainly disseminates self-pollens, a nearly arrival of such disseminator on trees, may increase the rate of self-fecundation and thus reduce fructification success.

Although this was not rigorously measured, failure of all trees to flower during the second year, in the Sudan-Guinea zone could be imputable to the fruit harvesting technique used by locals in this area. It was observed that while in the Sudan zone, fruits were collected without pruning the trees, this was not the case in the Sudan-Guinea zones. Pruning often results in reduction of photosynthetic capacity, and/or reallocation of resources or stored reserves from reproduction to vegetative growth (Gaoue and Ticktin, 2008).

Flowering length and active phase significantly differed between areas with different climatic conditions. Fruiting length and fruiting active phase were significantly longer in Sudan-Guinea zone (wetter zone) than in the Sudan zone while flowering length and flowering active phase showed the reverse trend. This suggests that the wetter the climate, the longer the fruiting length and active phase. This may be linked to; (i) larger size of fruits in wetter zones (Fandohan A.B., personal observations) so that they take longer to reach full size; (ii) earlier starting of the drought period or lower relative air humidity during that period in drier zones so that ripening takes place earlier. Results suggest a negative relationship between fruiting events and $D_{1.30}$: The larger the $D_{1.30}$ was, the lower the fruiting length was. This may be because larger trees gather faster, needed resources for reproduction due to a higher photosynthetic capacity and a more powerful root system. However, this hypothesis should be further confirmed.

Conclusion

This study provides information on the functional rhythms of *Tamarindus indica* in relation to climatic conditions. Climatic conditions seemed to significantly affect phenological events. Such information has several practical implications such as biotic indicator of climatic variations and may be relevant in predicting flowering and fruiting shifts in response to changes in climatic conditions. Nevertheless, interpretations should be taken with great caution because observed trends may result from many other confounded idiosyncratic and environment effects related to the life story of each tree, that is, past fire stress, disease, pest attacks, etc. In addition, successful fruiting in one year may be at the cost of vegetative growth so that some woody plants alternate supra-annual schedules of low and high production years (Kelly and Sork, 2002). Hence, further long-term phenological studies should address how far exploitation regimes, climatic factors, soils, and age of the trees affect inter-annual variation of phenological events and productivity of tamarind trees.

Conflict of Interest

The authors have not declared any conflict of interest.

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