SELECTION OF COWPEA (*Vigna unguiculata (L). Walp*) FOR HIGH YIELD UNDER LOW SOIL PHOSPHORUS CONDITIONS

By

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DECLARATION

I hereby declare that except for references to works of other researchers, which have been duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree

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ABSTRACT

Nitrogen (N) and phosphorus (P) are among the main edaphic factors that limit crop production in Sub-Saharan Africa (SSA). As a nitrogen fixing legume, cowpea production is not significantly affected by N, but P deficiency in soils. Two hundred (200) cowpea genotypes composed of both landraces and improved varieties were screened in the field under low P soil conditions in order to (i) determine genetic variability and heritability of traits associated with low P tolerance, (ii) assess the genotype by environment interactions for yield and its components under low P conditions, (iii) identify superior cultivars for use as varieties and/or as parents in improvement programs and (iv) determine the effects of planting date on the cycle and yield of local cowpea varieties in Niger. A participatory rural appraisal (PRA) was conducted to obtain farmers' knowledge and perceptions on low soil fertility and preference for cowpea varieties. The PRA results revealed that 11, 49 and 40 % of respondents claimed that their farms are respectively very low, low and high in fertility. About 75 % of farmers indicated that their cowpea production was low. Drought and low soil fertility were identified as the major production constraints. In terms of varietal preferences, early maturity and high yield potential were the traits preferred by farmers. High diversity with regards to yield and yield related traits under low soil P conditions was detected in the evaluated germplasm. High estimates of heritability, genetic variance, phenotypic variance as well as GCV and PCV were obtained in rainy season in comparison to dry season. The mean number of days to flowering, days to 50 % maturity, plant height, fodder yield, harvest index and hundred seed weight were the most highly heritable traits with 92.51 %, 85.02 %, 70.56 %, 80.6 %, 80.72 % and 71.94 % broad-sense heritability estimates, respectively. Grain yield was positively correlated with shoot dry weight, plant height and shoot color ; it was however negatively correlated with days to flowering and days to 50 % maturity. Genotype x Environment interaction was only significant for days to flowering, days to 50 % maturity and fodder yield. The contribution of genotypes to the variation was high regarding fodder yield and days to flowering, but medium with regard to grain yield. Genotypes with high grain and fodder yield under low P soil conditions were detected; nevertheless, only G150 was stable across the test environments. The largest contribution of genotypes to traits variation was observed in fodder yield (46.76 %) while the smallest was in shoot dry weight (1.5 %). Genotypes were also responsible for a significant variation with regard to days to flowering (21.57%) as well as grain yield (15.06 %). The environment was the main cause of the variability detected in shoot dry weight, plant height, days to 50 % maturity and grain yield with 82.45 %. 72.04 %. 58.69 % and 36.55 %, respectively. The GEI part of the variation was high in days to flowering (36.85 %). fodder yield (22.73 %) and days to 50 % maturity (18.66 %). The G x E interaction although not significant for grain yield, contributed considerably (15.85 %) to the yield variation.

Planting date had a significant effect on yield and yield related traits of local cowpea cultivars in Niger. Significant reduction in days to flowering and days to 50 % maturity with subsequent decrease in grain and fodder yield was observed when varieties were planted late. The first planting dates recorded the highest mean grain yield in both 2016 and 2017 while the lowest belonged to last planting dates. G56 and G34 were the best and worst performing genotypes with respectively 40.47 and 1.78 g grain yield per plant across the test environments. Superior genotypes in terms of fodder yield were G35, G78 and G74 with 178.50, 173.63 and 167.37 g per plant, respectively.

Cultivars tolerant to both low P soil conditions and striga were also identified.The population developed for recurrent selection and QTL detection is at F2 generation. Candidate Genotypes for release as variety were identified.

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DEDICATION

I dedicate the present work to my father (Elhadj Souleymane Soli) and mother (Khadidjatou Sara) for their indefatigable effort in shaping me into the person I have become.

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Table of contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABU: Ahmad Bello University

AGRA: Alliance for Green Revolution in Africa

AMMI: Additive Main Effect and Multiplicative Interaction

ANOVA: Analysis of Variance

CV: Coefficient of Variation

FAO: Food and Agricultural Organization

GCV: Genetic Coefficient of Variation

GE: Genotype by Environment

GEI: Genotype by Environment Interactions

GGE: Genotype and Genotype by Environment Interactions

IAR: Institute of Agricultural Research

ICRISAT: International Crop Research Institute for the Semi-Arid Tropics

IITA: International Institute for Tropical Agriculture

INERA: Institut de L'Environment et de Recherches Agricoles

INRAN: Institut National de la Recherche Agronomique du Niger

PCV: Phenotypic Coefficient of Variation

PRA: Participatory Rural Appraisal

PPB: Participatory Plant Breeding

PVS: Participatory Varietal Selection

QTL: Quantitative Trait Locus

USA: United States of America

WACCI: West Africa Centre for Crop Improvement

CHAPTER ONE

1.0. INTRODUCTION

Cultivated cowpea, *Vigna unguiculata* [L. Walp] is an annual crop (2n = 22) that belongs to the family fabaceae. It is a seed-pod crop adapted to warm agro-ecology and susceptible to chilling. It can be cultivated in areas with annual rainfall ranging from 500 to 1200 mm, however extra-early and early varieties can be grown in zones having less than 500 mm (Dugje *et al*., 2009). As one of the most important leguminous crops in the dry savanna areas of Sub-Saharan Africa, cowpea provides food, fodder and cash to farmers. Its leaves and grains are of high nutritional value with a mean protein content of about 26 % (Ibro *et al*., 2011), making it the cheapest source of dietary protein to small scale farmers. The high amount of antioxidants in its grain contributes in lowering the risk of cancer (Mahamane *et al*., 2008). In the Sahel, cowpea is a key component of agricultural systems as it is mostly grown in association with cereals especially millet and sorghum. It is a source of fodder needed to sustain a crop-livestock integration system practiced by small scale farmers through out the semi-arid zone. In some areas, farmers living around the urban zones grow cowpea just for fodder due to its high price in cities as it is used for fattening sheep and goat. Cowpea plays a significant role in the improvement of soil fertility as it replenishes nitrogen of the soil. Studies have shown that the presence of legumes such as cowpea in cropping systems is a cheap alternative to improve soil fertility and subsequently yield. It is also used as a cover crop for the prevention of wind and water erosion.

Cowpea is grown widely in Africa, Asia and America. World production amounts to 5,718,145 tons over an area of 11,316,145 ha (FAOSTAT, 2014). Niger Republic with an average production of 1,000,000 tons over the last five years is the second largest cowpea producing country in the world after Nigeria. In Niger, cowpea has become the second crop in terms of production after millet (FAOSTAT, 2014) and the most important legume as a result of the drastic decline in groundnut production. In the last decade, cowpea has become a major cash crop and occupies about 90 % of area allocated to leguminous crops thereby improving significantly the income level of small scale farmers (Ibro *et al.*, 2007). About 70 % of its production is exported mainly to neighbouring countries; consequently, it is among the main sources of Niger's foreign exchange with 27 % of the total agricultural export.

Crop production in general and cowpea in particular has been dwindling due to many limiting factors. These factors are the main causes of the observed low yield across cowpea producing areas in the semi-arid areas of the tropics. The mean grain yield is about 324 kg/ha across major world cowpea production countries (Singh *et al.*, 2002). In Niger cowpea yield ranges from 68 to 388 kg/ha from 2000 to 2012 with a mean of 208 kg/ha (INS, 2013). This yield is low even though it is obtained from a mixed cropping system where cowpea shares the same field with millet or sorghum. The low grain yield is compounded by several factors such as insects, diseases and parasitic weeds as well as poor soil conditions, the use of unimproved varieties, inadequate and poor cultural practices (Rachie, 1985).

Low soil fertility is among the most important abiotic factors that cause severe setbacks in cowpea production. Many studies have concluded that in the driest zones of the Sahel and other parts of West Africa, low soil fertility causes yield reduction more than rainfall (Payne, 1997).

In Niger, only about 1/3 of the country's land area is suitable for agriculture. Agricultural soils, especially upland soils are generally poor, acidic (4.5 to 6.0 pH), have low content of organic matter (0.1 to 0.7 %) and deficient in P with a bray-1 P varying from 0.4 to 3.4 mg/kg (Nouri *et al.*, 2016). The soils are predominantly sandy with low silt and clay content (Republique du Niger, 2001). However, soils with low clay content and kaolinite's low activity tend to contain high free iron oxide to clay fraction that make inherent P fixed or blocked by iron forms such as goethite (West *et al.*, 1984). Apart from P, N is another deficient macroelement that limits crop production in Niger. Cowpea being a legume has the ability of fixing nitrogen, its production is not therefore affected by N deficiency in soils, however low P content in soils could hinder N fixation of leguminous crops (Krasilnikoff *et al.*, 2003; Jemo *et al.*, 2006; Qiao *et al.*, 2007). P plays a major role in crops shoot and growth, respiration, photosynthesis, flower initiation and fruit development (Theodorou and Plaxton, 1993; Schachtman *et al.*, 1998; Uchida, 2000).

The low P nature of agricultural soils in Niger could therefore be a major edaphic factor responsible for the observed low cowpea yield in the country. Several methods of improving P levels of the soil and/or its availability to crops were reported in literature. These include application of compost (Nelson and Nikkelsen, 2008; Verma *et al.*, 2013), poultry manure (Yu *et al.*, 2013), crop residues (Fuller *et al.*, 1956,), rock phosphate (Bationo *et al.*, 2002; Saidou *et al.*, 2011) as well as mineral P fertilizers (Saidou *et al.*, 2007; Odundo *et al.*, 2010; Oladiran *et al.*, 2012; Haruna and Usman, 2013; Nkaa *et al.*, 2014).

Adoption of these technologies by farmers was however limited as a result of many socio-economic constraints. Compost and animal manure application are conditioned by their availability, labour as well as distance of farms from villages. Williams *et al.* (1999) reported labour requirement and availability, farm size, farm ownership and its distance from villages are prerequiste to organic residues utilization. The situation may become worse in future with the increased pressure on arable land due to the slow but steady spread of the desert, high population growth rate, exponential urbanization and overgrazing. In almost all crop growing areas of the country, the fields are now continously farmed until it is worn out, leading to complete depletion of soil nutrients and other forms of soil degradation. Crop residues that can help in resuscitating soil nutrients are completely collected from farms for livestock feeding, fuel and housing. Furthermore, erosion caused by wind and rainfall add to the problem by sweeping the top soils since the fields are left bare with no cover. Also P mineral fertilizer application is limited by low income of farmers, restricted access to credits, as well as low level of education (Abdoulaye and Sanders, 2005; Kelly, 2005; Ndjeunga and Batalian, 2005).

Under low P soil conditions, adoption of tolerant varieties could be a good alternative for resource poor farmers and environmental preservation as well. Significant genotypic variations with regards to P uptake and P use efficiency have been found in rice, wheat, clover and maize (Trolove *et al*., 1996; Romer and Schenk 1998). Yan *et al*. (1995) reported that legumes vary in their P use efficiency with respect to growth and yield. Genotypic variability has been found in pigeon pea (*Cajanus cajan*) and common bean (*Phaselous vulgaris*) regarding their ability to acquire P (Subbarao *et al*., 1997; Bonser *et al*., 1996). In cowpea large varietal differences with respect to adaptation to P deficient soil conditions were reported (Mahamane *et al*., 2008; Vesterager *et al*., 2006; Krasilnikoff *et al*., 2003; Oladiran *et al*., 2012; Alkama *et al*., 2009; Jemo *et al*., 2006; Saidou *et al*., 2007; Ojo *et al*., 2007). Researchers have taken advantage of that variation and developed mapping populations in order to identify quantitative trait loci associated with low P soil tolerance. Rothe *et al*. (2014) reported three SSR markers namely CLM0269, 221/222, and CLM0298 linked to low P soil tolerance in cowpea. In addition, Ravelombola *et al.* (2017) screened 357 USDA cowpea lines for high performance on P deficient soil conditions and response to rock phosphate and found ten and eight QTLs linked to respectively low P tolerance and rock phosphate use efficiency. Despite the inherent low P nature of most agricultural soils in Niger, that is being aggravated by continuous cultivation of fields, farmers' socio-economic conditions and some of their practices, as well as low availability and high price of P fertilizers, very little attempts have been made to develop cowpea varieties adapted to P deficient soil conditions. The general objective of the present work was to select cowpea lines with tolerance to low P soils conditions. The specific objectives were to:

i) Evaluate farmers perceptions on low soil fertility and determine their cowpea varietal preferences;

ii) Determine genetic variability and heritability of traits associated with low P tolerance;

iii) Assess the genotype by environment interactions for yield and its components under low P conditions and

iv) Identify superior cultivars for use as varieties and/or as parents in improvement programs.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Origin and domestication of cowpea

The origin of cowpea has been controversial as different centers were suggested by many authors. The centers proposed include India (Faris, 1964), Persia (Wright, 1907), South America (Piper, 1913) and Africa (Ames, 1939). However, Fery (1990) stated that the majority of the evidence published recently indicates Africa as center of origin of cowpea. Wild *Vigna* species center of diversity is located in Southeastern Africa (Ng and Padulosi, 1988, Padulosi *et al.*, 1997). With regards to cultivated cowpea, its center of highest diversity is the Nothern Guinea Savanna of West Africa. Steele (1972) believes that *Vigna unguiculata* originated from West Africa since the subspecies dekindtiana which is most cross-compatible with cultivated cowpea is found exclusively in that region.

V. unguiculata was a perennial and predominantly outbreeding crop; however it has changed to annual and inbreeding growing habit through the process of evolution according to Ng (1995). Evolving from species dekindtiana, cultivated cowpea experienced the loss of seed dormancy, pod dehiscence, pod and seed size along with an increase in yield through the process of domestication, selection and cultivation. Although the evidences showed cowpea domestication took place in Africa, the precise location where it was domesticated in Africa is not certain. According to Ng and Maréchal, 1985, Ethiopia, Central Africa, Central and South Africa as well as West Africa were among the possible centers of domestication. Similarly, Padulosi and Ng (1997) postulated that cowpea could have been brought under cultivation in any part of Sub-Saharan Africa taking into account the fact that variety dekindtiana is widely spread in that region.

Nevertheless, Ehlers and Hall (1997) stated that West Africa was the first center of cowpea domestication. Their claim corroborates with the findings of Ng (1995) who asserted that the greatest diversity of cultivated cowpea is found in the Northwest of Cameroon, part of Burkina Faso, Savanna of Nigeria, Northern Benin, Togo and Southern Niger. Based on archaeological findings from carbon dating of wild or cultivated cowpea of Kimtampo rock shelter, central Ghana is so far the eldest place where cowpea was discovered (Flight, 1976). Archaeological evidence showed that cattle existed in West Africa since 3000 BC (Clutton-Brock, 1989) and probably early African farmers used wild cowpea as feed for their cattle. Ng (1995) hypothesized that the domestication of the cowpea cultigroug *unguiculata* occurred in West Africa as far back as 2000 BC. Cowpea was undoubtedly brought the first time to India during the Neolithic period (Pant *et al*, 1982) and its large genetic variation existing in that region suggests that it is the secondary center of the crop diversity. Cowpea was brought to Europe via North-eastern Africa about 300 BC, to tropical Americas in the 17th century and to Southern USA in 18th century (Padulosi and Ng, 1997)

2.2. Classification of cowpea

Cowpea, an herbaceous dicotyledonous plant, is a member of the order *Fabales*. It belongs to the family *Fabaceae*, subfamily *Faboideae*, tribe *Phaseoleae*, subtribe *Phaseolineae*, genus *Vigna* and section *Catiang* (Maréchal *et al.*, 1978). There are many species in the genus *Vigna*, its numbers however differ among authors. One hundred and eighty four species were reported by Phillips (1951), 150, 154 and 84 by Verdcourt (1970), Steele (1972) and Marechal *et al*. (1978) respectively. Other members of the *Vigna* species apart from cowpea are blackgram (*V. mungo*), mungbean (*V radiata*) and adzuki bean (*V. angularis*). Cowpea has strong similarities with *Phaseolus* and *Dolichos*. Maréchal *et al*. (1978) asserted that genus *Vigna* was at first divided into many subgenera on the basis of morphological features, degree of genetic hybridization/reproductive seclusion and geographic dissemination of species. The subgenera *Vigna* and *Haydonia* from Africa, *Ceratotrophis* from Asia and *Sigmoidotropis* and *Lasioprom* from America are the main groups. However, among all the cowpea subgenera, only *Vigna unguiculata* which is subdivided in four cultigroups is under cultivation. The cultigroups are *unguiculata, biflora, sesquipedalis* and *textilis* (Ng and Maréchal, 1985).

Apart from cultivated cowpea, wild cowpea relatives exist within the genus *Vigna.* Padulosi (1993), reported that more than 400 wild *Vigna unguiculata* were characterized at IITA; that work along with study of live materials *in situ* and samples from main European and African herbaria as well as cytological investigations brought about the discovery of new taxa and a modification of the nomenclature of some species (Ng, 1995). The species *dekindtiana, tenuis* and *stenophylla* were classified under the *Vigna* (Padulosi, 1993, Padulosi and Ng, 1997, Maréchal *et al*., 1978) while variety *protacta* and *pubescens* were placed into two distinct subspecies owing their hair possession in pods and other plant parts as well as leaves, flowers, pollen and grain morphology and their root systems. In this classification system, new varieties such as *grandiflora, huillensis, ciliolata* and *congolensis*, were added to subspecies *dekindtiana*, however varieties *parviflora, oblonga* and *tenuis*, were distinguished in subspecies *tenuis* while *protrata, rhomboidea kgalagadiensis* were recognized within the subspecies *protracta.*

2.3. Biology and agronomy of cowpea

At germination, the two leaves of cowpea, above the cotyledon, are simple and opposite, but the subsequent trifoliate leaves are alternate. The shape of cowpea leaves is either globose, sub-globose, hastate/lanceolate or sub-hastate (http://genebank.iita.org). The plants are of various types and they are classified as erect, semi-erect, prostrate, semi-prostrate and climbing. Cowpea growth habit ranges from indeterminate to determinate with the indeterminate habit being predominant. Most varieties are tap rooted with few lateral roots.

The peduncles stemming from the leaf axis support the raceme which in turns bears the flowers. The flowers are of white, yellow, red or purple color. There is a relationship between flower and coat color according to Saunders (1960). With regards to the pods form, it can be straight, curved or coiled. In general fresh pods are green in color, but some can be partially or completely purple or black as a result of anthocyanin content (Harland, 1919). Cowpea seeds have generally kidney form, however when it is limited in the pod, its shape turns to globular. Seeds are usually of medium size, but genotypes with small or large seed size do exist. With respect to seed coat, it can be smooth or wrinkled while its color may be white, red, cream, green, buff, brown, black , speckled, mottled or blotchy. Many are labelled as eyed (blackeye, pinkeye purple hull etc.) whereas the white colored helium is delimited by a different color (Davis *et al.*, 2010).

Cultivated cowpea differs considerably from its wild relatives but it shares some similarities in terms of morphology and growth habit. Among the wild cowpea, variety *dekindtiana* is the most closely related to cultivated cowpea landraces, however they are significantly different with regards to color, size and smoothness of the mature pods as mature pods of *dekindtiana* are small, black, scabrous, shatter and contain tiny, dark speckled or solid black seeds resembling those of other wild varieties (Padulosi and Ng, 1997). There is no dormancy in cultivated cowpea (Ezedinma *et al., 1962*) while its wild relative's seed have to be scarified to enhance germination as a result of some levels of dormancy (Stanton, 1961). In suitable moisture conditions, the germination of cultivated cowpea seeds occurs within 4 to 5 days after planting (DAP). Flower bud initiation depends on the variety growth habit as well as its reaction to photoperiodism. In general, determinate varieties are early maturing while the indeterminate ones mature late. Most determinate varieties start flowering from 4-5 weeks after planting, reach the peak at 7 weeks whereas flowering begins at 7 weeks in the case of indeterminate genotypes. With regards to cycle, cowpea varieties are classified as extra-early,

early, medium and late maturing. Extra-early varieties reach maturity within 60-69, early around 70-79, medium in 80-89 and late in 90-120 DAP (Dugje *et al.*, 2009).

2.4. Distribution and production

Cowpea is a versatile legume crop that tolerates to a large extent harsh climatic conditions. It is cultivated worldwide, however, large number of producing countries do not store production data. In most developing countries, reliable data with regards to agriculture can only be obtained from FAOSTAT. In 2014, cowpea was produced in 42 countries and its world production amounted to 5, 602, 715 tons over a total area of 12, 6 million hectares (FAOSTAT, 2017). Africa, to which the seven top producing countries belong, is by far, the leading continent in terms of cowpea production and the bulk of the production comes from West Africa (Table 2.1.).

Table 2.1 Top 20 world cowpea producing countries in 2014

Rank	Country	Production (tons)	Area (ha)	Yield (Kg/ha)
1	Nigeria	2. 137.900	3. 701.500	578
2	Niger	1. 593.166	5. 325.168	299
3	Burkina Faso	573.048	1. 205.162	475
4	United Republic of Tanzania	190.500	197.323	965
5	Cameroon	174.251	209.019	834
6	Mali	149.248	353.382	422
7	Kenya	138.673	281.877	492
8	Myanmar	115.200	132.000	873
9	Mozambique	103.837	377.900	275
10	Sudan	80.000	260.000	308
11	D R C	70.042	159.945	438
12	Senegal	64.088	153.142	418
13	Malawi	35.903	81.753	439
14	Haiti	29.895	41.525	720
15	United States of America	21.591	12.060	1.790
16	Peru	17.588	12.779	1.376
17	Serbia	16.189	4.777	3.389
18	Sri Lanka	15.281	11.519	1.327
19	China, mainland	13.500	13.000	1.038
20	Uganda	10.100	25.000	404

Source: FAOSTAT, 2017.

Nigeria, Niger and Burkina with 2,137,900, 1,593,166 and 573,048 tons respectively, are the major producing countries and account for 77 % of the world production.

2.5. Constraints to production

Cowpea production is subject to complex biotic and abiotic limiting factors that severely reduce its yield. The average yield in the world in 2014 is 444 kg/ha (FAOSTAT, 2017), it is very low compared to the potential which was reported to be more than 3000 kg/ha by Singh *et al*. (1997). The biotic constraints include insects, diseases and witch weeds. However insects appear to be the most common and serious biotic enemy of cowpea both on the field and in storage. Fatokun (2002) stated that at each stage of development, there are one or more main insects that attack cowpea and impede its development with subsequent negative effect on the yield. *Aphis craccivora*, for example attacks cowpea at seedling, flowering and pod stage and is believed to be one of the major pest of cowpea in Africa, Asia and Latin America (Jackai and Daoust, 1986). Drought, heat, low soil fertility and poor use of improved varieties are among the critical abiotic factors which badly dwindle cowpea production. In the semi-arid of the tropics, an area characterized by erratic rainfall, drought is a foremost cause of poor crop yield, however according to Payne *et al* (1997), poor soil fertility bring about yield loss more than drought in the driest parts of the Sahel and other areas of West Africa.

2.5.1. Soil fertility and mineral fertilizer utilization

The bulk of cowpea production comes from the West African Semiarid Tropics (WASAT). This zone is characterized by inherent low soil fertility as a result of low levels of organic carbon (generally less than 0.3%), poor total and available phosphorus and nitrogen, as well as low effective cation exchange capacity (ECEC) (Bationo *et al.*, 2002). Organic matter contributes significantly to soil fertility since it contains around 70 to 80 and 60 to 70% of nitrogen and phosphorus respectively. Soil of the WASAT not only tend to be sandy and low in pH, organic-matter content, N, P and K availability, water holding capacity, and cation-exchange capacity (CEC) but also its clay mineralogy is largely kaolinitic (Jones and Wild, 1975; Weil, 2000; Wong *et al.*, 1991; Casenave and Valentin, 1992; Manu *et al.*, 1996; Rockström *et al.*, 1998; West *et al.*, 1984). Soils with low clay content and kaolinite low activity tend to have a high ratio of free iron oxide to clay, causing much of the native P to be fixed or occluded by iron forms such as goethite (West *et al.*, 1984). In the past three decades, around 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} has been lost on average from approximatively 200 million hectare of farmland in 37 African countries. Soil N and P can be restored through the use of fertilizers and organic matter. However while N is mainly replenished via organic matter, P is mostly restored through the use of mineral fertilizers (Sanchez *et al.*, 1997). However, the striking point is that both mineral and organic fertilizer are used in extremely small quantities resulting in very low amount applied per ha and slow increase of the rate of consumption (Kelly and Naseem, 2009). Most farmers cannot afford it due generally to its high cost and poor availability (Trolove *et al.*, 2003), a situation that persisted for decades (Payne, 2006). With an average rate of 10 kg/ha, SubSaharan Africa is the world area where chemical fertilizer is less used (McIntire (1986); the whole continent consumption represents only 2 to 3% of that of the world (Kelly and Naseem, 2009). The situation is even worse in Niger where only 1 kg/ha were used (Pender *et al.*, 2008). With regard to P fertilizers utilization, Africa accounts for less than the quarter of that the world (Lott *et al.*, 2011). In Niger mineral P application is very low; NPK is the most popular P fertilizer, however its utilization is limited by many socio economic constraints. The world has a considerable reserve of rock phosphate (RP) that can be used as source of good quality as well as relatively low cost phosphorus fertilizer. The largest world deposit of RP is found in Morocco and Western Sahara (US Geological Survey, Mineral commodity summaries 2014). In West Africa there are ample sedimentary deposits of rock phosphate of varying quality (Pieri, 1990, Sanchez *et al.*, 1997). Niger is blessed with large amount of natural rock phosphate reserve in Tahoua region.

2.5.1.1. The soil phosphorus problem

Erosion, leaching, crop uptake, crop removal as well as runoff are the major causes of phosphorus lost from the soil. The concentration of P in the tissues of plants varies from 0.1 to 0.5 % on a dry weight basis (Mullins, 2009). When phosphorus is utilized by crop roots or lost via runoff, part of the sparingly soluble P becomes available through the solid soil phase (McDowell *et al.*, 2001). This process is regulated by the equilibrium between the soil adsorption system, soil solution and precipitated P compounds (Sample *et al.*, 1980). Applied P fertilizer changes to low soluble or insoluble forms through a process known as fixation. The fixation of phosphates by Fe, Al, and Ca is among the main factors that cause low phytoavailability (McBeath *et al*., 2005), because at least 70–90% of P that enters the soil is fixed, making it difficult for plants to absorb and use (Kou *et al*., 1999; Lei *et al*., 2004; Liu *et al*., 2000).

Both dissolved and eroded soil particles forms of soil phosphorus may be carried away by water that moves across earth surface and could increase the concentration of bioavailable P in surface water namely rivers, streams, lakes and oceans (Mullins, 2009, Bomans *et al*., 2005). This will result in eutrophication which is waters overenrichment with mineral elements. The consequences are high production of autotrophs, such as cyanobacteria and algae (Bomans *et al.*, 2005, Correl, 1998, Carpenter *et al.*, 1998). The removal of P through leaching is viewed as less important compared surface runoff because soils, namely phosphorus-deficient subsoils held P very tightly. However, the potential of P leaching may increase in the case of soils with high water tables as well as phosphorus-saturated soils (Mullins, 2009).

2.5.1.2. Forms of phosphorus in soils

Phosphorus is a mineral element that is highly immobile in the soil. It reacts with soil elements such as iron (Fe), aluminum (Al) and calcium (Ca) to form stable compounds. It therefore exists most often in non-available forms or in forms that become available only outside of the rhizosphere (Schachtman *et al.* 1998). Phosphate in the soil is either in organic or mineral forms.

Inorganic P is exceedingly reactive. It is present in the lithosphere in more than 150 different mineral forms. These minerals are variable with regard to their solubility and ability to supply the soil solution with P. Mineral P solubility is affected by pH, the concentration of Al, Fe, Ca and magnesium (Mg), the behavior and surface area of soil particles and soil moisture content. On the other hand, organic P is composed of relatively labile phospholipids, nucleic acids, inositols, fulvic acids and humic acids (McDowell *et al*., 2001). Phosphorus is however, most often present in the organic form in the soil. Richardson (1994) reported that nearly 80 % of the phosphate found in the soil is in the organic form. Phytic acid (inositol hexaphosphate) is usually a principal component of organic phosphate; the other part is made up of inorganic fraction that contains 170 mineral forms of P. About 80 % of P in the soils turns out to be immobile and non-available for plant use as a result of precipitation, adsorption or conversion to the organic form (Holford, 1997). Plants take up P from the soil solution in the form H_2PO_4- and $HPO_4^{2-}$when soil pH is respectively below 7.2 and pH above 7.2. Labile P is available to plants while non-labile P is not. Immobile P is released into soil solution as a result of the decomposition of soil minerals through weathering, but the process is gradual. Acid soils contained iron and aluminum phosphates, while calcareous soils, octacalcium phosphate and apatite are found in neutral soils. P is low available in soil because it moves mainly through diffusion while minerals that are more available move through the soil via bulk flow and diffusion. P diffuses slowly at the rate of

10^{-12} to 10^{-15} m^2 s^{-1}, a zone depleted of P occurs around the roots when plant absorption rates are high (Schachtman *et al*. 1998). Decomposition of the organic matter by soil microorganisms releases a considerable amount of phosphorus to soil. The mineralization of P by microorganisms linked to organic matter is crucial in preserving P levels in soil solution.

2.5.1.3. Phosphorus availability to plants

Available P refers to P pool readily available to plant (Holford, 1997). The form of P most readily available to plants is Pi (McDowell *et al.*, 2000) and most of the times, its concentration do not go beyond 10 µM in soil solutions (Bieleski, 1973). Breeuwsma *et al.*, 1995, cited by McDowell *et al.*, 2000, reported that Dutch scientists extracting soil with acid ammonium oxalate found that the molar concentration of P was in correlation with the average concentration of Al and Fe on a molar basis, and multiplied by 100, gave a degree of P saturation (DPS). Sardans *et al.* (2006) studied the effect of warming and drought on soil phosphatase activity and soil P availability in a Mediterranean shrubland. Their results revealed that warming without significant changes in soil water content leads to an increase in mineralomass accumulation with subsequent high microbial activity, and the combine action of these two factors results in the reduction of the total and available soil-P contents. However under drought conditions, plant growth and P demand reduce resulting in a rise in Pi availability. Zahedifar *et al.* (2011) investigated the effect of phosphorus and organic matter on soil-plant phosphorus relationships in spinach and found out that soil P content is higher in all organic matter treatments particularly at 6th weeks after emergence. Furthermore, they realized that P uptake is greater in treatment that received organic matter without P than where P was applied. In some soils organic phosphorus can contribute 50 percent of the available phosphorus. Organic matter application on phosphorus adsorption of three soil parent materials namely basalt, granite, and river alluvial deposits, was studied

(Yu *et al*. 2013), the result revealed that organic fertilizers available P was significantly higher in all treatment groups compared after the addition .The release of soil P to plant roots is influenced by many chemical and biological processes such as soil temperature, texture, aeration and compaction, moisture, pH, mineralogy, crop residues, organic matter, effect of plant roots, effect of mycorrhizae and interaction with other nutrients (Mullins, 2009, Armstrong *et al.*, 1999). Low soil temperature, low pH, moisture stress, low organic matter, limited oxygen supply as well as low mycorrhizae population in the soil negatively affect phosphorus availability to plants.

2.5.1.4. Phosphorus function in plants

There are 17 essential mineral elements for plant growth which roles cannot be accomplished by any other element. P is one of these nutrients and is considered as a major nutrient. It is needed by crops in relatively sizable quantities (Armstrong *et al*. 1999), however, P is often deficient for crop production. P is a major macronutrient for plant and accounts for about 0.2% of a plant's dry weight. It is reported to be a key component in molecules such as ATP, phospholipids and nucleic acids (Schachtman *et al*. 1998). As such, it plays an important role in the storage and transfer of energy in the form of ADP and ATP (adenosine di- and triphosphate) and DPN and TPN (di- and triphosphate) during photosynthesis and respiration. Pi is associated also in the control of key enzyme reactions and in the metabolic pathways regulation (Theodorou and Plaxton, 1993). Phosphorus is essential for plant development and it is part of every living plant cell (Schachtman *et al.* 1998). According to Grant *et al.* (2001), plants need an adequate supply of P from the early stage of development for optimum crop production. The highest concentration of P in a mature plant is found in seeds. Metabolism and cell division are high in young cells such as shoots and roots tips, hence it needs P in large amount. P helps in root, seeds and fruits development, it is also involved in flower initiation. P is reported to lower disease incidence and increase the quality of some crops (Uchida, 2000).

2.5.1.5. Phosphorus deficiency symptoms

The description of the classic deficiency symptoms for phosphorus or other nutrients in crops can be readily done, but symptoms are not always so clear in the field. Sometimes, other conditions can complicate the appearance causing thereby difficulty in diagnosis. Interactions involving more than one nutrient may also affect appearance of symptoms (Armstrong *et al.*, 1999). Phosphorus deficiency symptoms may vary from one crop to another, but the general symptom is slow, weak and stunted growth. For example while phosphorus deficiency may delay blooming and maturity in soybean, premature senescence of leaves may occur on P-deficient cotton plants later in the season. The appearance of reddish-purple color indicates P deficiency in plants, but sometimes it occurs as a result of sugars accumulation which causes the development of anthocyanin pigments. The development of reddish-purple color may also be a normal plant characteristic. Red-purple color induced by P deficiency can be noticed during early spring on low P sites, but usually this symptom persist only under extrem low P soil conditions. As a mobile element, P can be moved to sites of new growth, leading to the appearance of dark to blue-green coloration on older leaves of some plants. P deficiency may sometimes resemble N deficiency when plants are small, especially under cold temperatures that limit the extension of roots with subsequent reduction in P uptake. When the soil warms, deficiencies may disappear. Delayed maturity as well as poor seed and fruit development occur when crops are grown under low P soil conditions (Armstrong et *al*. 1999, Uchida, 2000).

2.5.2. Impact of phosphorus on crop performance

Soil fertility is essential for optimum crop growth and development as well as the production of adequate food quantities. Undoubtedly, low fertile soils cause low crop productivity

(Omotayo and Chukwuka, 2008). The poor crop yield in Africa is associated with low soil fertility in nitrogen as well as low soil availability of phosphorus. Low soil fertility is widely spread across the crop growing areas of sub-Saharan Africa. It is reported that reduction in soil fertility of smallholders' farms is the major biophysical cause of low food production in Africa (Sanchez *et al.*, 1997). Low soil fertility especially in N and P has been identified by researchers as one of the main abiotic limiting factor to African agriculture (Sanchez *et al.*, 1997). After N, P is the second most frequently limiting macronutrient for plant growth (Schachman *et al.*, 1998). Phosphorus is the 11th most abundant element in the earth crust, its supply is however limited (Syers *et al.*, 2011). It is among the macronutrients that play a major role in plant growth and development. Owing to P significant impact on crop yield, its availability to plants is crucial for food production. A soil with plant available P content less than 40 mg kg-1 (determined by Bray-1 method) is regarded as P deficient (Mourice and Tryphone, 2012). Adequate P supply leads to increase grain production, high quality crop, greater stalk strength, more root growth and early crop maturity (Beegle and Durst, 2002), thus it is essential for achieving and maintaining food security. Agriculture accounts for about 80 to 90 % of world demand of phosphorus and it is globally the main user of that macronutrient (Tirado and Michelle, 2012). Agricultural production is constrained in many parts of the world by the shortage of available P to plants (Frossard *et al.*, 2009). As stated by Grant *et al.* (2005), crop production is restricted by limited P supply at the early season. Similar results have been reported on many crops species. On corn, enhanced early-season P supply leads to higher partitioning of dry matter to grain (Gavito and Miller 1998a), higher grain yield (Barry and Miller 1989; Lauzon and Miller 1997). The effect of P supply before 6 weeks of growth on wheat and barley grain yield is much greater than when it is applied later. In early-season, P deficiency results in growth reduction in radish and lettuce (Avnimelech and Scherzer 1971), broadleaved willow (Atkinson and Davidson 1971), wheatgrass (Boatwright and Viets 1966) and a variety of other crops (Crafts-Brandner 1992; Elliott *et al*. 1997).

2.5.2.1. Impact of phosphorus on legumes and cowpea

Legume crops have the ability to fix N from the air, but its optimum development as well as nitrogen fixation depend strongly on soils adequate supply of phosphorus. Apart from P, a good balance of micronutrients (iron, sulfur, and molybdenum), appropriate pH, and good aeration is also necessary (Valenzuela and Smith, 2002). The production of legumes is not constrained to a large extent by nitrogen deficiency in the soil. Rock phosphate application on P deficient soils of West African humid zone has been reported to enhance biomass and N accumulation in *C. micans*, a root-nodulating N-fixing legume (Somado *et al., 2006)*. Common bean yield is reduced by 60% when it is grown on soil deficient in plant available P (Acosta-Díaz *et al*., 2009). P deficiency in soil is among the most limiting soil fertility factors to cowpea production (Bationo *et al*., 2002). Nkaa *et al.* (2014) studied the effect of phosphorus fertilizer on the growth and yield of cowpea. They found out that P significantly influences cowpea yield and growth parameters. They reported improved plant height, leaf area, number of leaves and number of branches in all the weeks of measurement with P application. Similarly Odundo *et al*. (2010) while investigating the effect of phosphorus on survival, P accumulation and yield of cowpea varieties across a soil fertility gradient in western Kenya deduced that P application is essential for enhanced dry matter accumulation and yield. Phosphorus positively impacts on grain yield, number and dry weight of nodules, shoot and root dry weight, total biomass, number of pods per plant as well as the total N and P uptake in cowpea (Oladiran *et al*., 2011, Singh *et al*., 2011, Asuming e*t al*., 2013). Similar results were reported by Audu *et al.* (2013) who reported that Sokoto Rock Phosphate (SRP) application raises the quantity of P available to plants in the soil resulting in increment in grain yield and fodder. They then suggested the application of SRP at the rate of 75 kg/ha if the soil pH is below 6.5. Greater amount of nitrogen is fixed by cowpea following P application (Fongi and Begoude, 2014). Saidou *et al.* (2011) reported that rock phosphate application increased AMF infection of cowpea roots. The application of P at the rate of 30 kg/ha increases dry matter production in cowpea by 74 % in comparison to the control (Odundo *et al, 2010*), they also noted significant rise in grain yield with 15 kg/ha P supply. Resource poor small scale farmers are now dealing with low crop yields as well as income and food scarcity as a result of low soil available P in most of SSA soils (Verde and Matusso, 2014). Adequate action should thus be taken to prevent food problem and poverty in the near future.

2.5.3. Adaptation of cowpea to low P soil conditions

Cowpea is a legume crop that is adapted to harsh climatic conditions such as drought and low soil fertility. The ability of this crop to fix nitrogen from the air allows it to have good performance on low fertile soils. However the lack of available phosphorus in the soil negatively affects the nitrogen fixing capacity of cowpea. The combine effect of N and P deficiencies results in significant reduction of the crop grain and biomass yield. Improvement in yield can be achieved through phosphorus fertilizer application, unfortunately the released P is rapidly bound by Fe and Al oxide, and consequently it becomes unavailable for plant use.

Several research findings have revealed variability among crop species and cultivars regarding specific nutrient elements uptake and use efficiency, phosphorus included, as a result of several morphological, physiological and biochemical mechanisms (Hoffland *et al.*, 1989; Raghothama, 1999; Neumann and Römheld, 1999; Akhtar *et al.*, 2007). Large genotypic difference associated with P acquisition and P use efficiency has been detected in many crops such as rice, wheat, clover and maize (Trolove *et al.*, 1996; Romer and Schenk 1998). A major quantitative trait locus (QTL) named Pup1 for P use efficiency was identified in Kasalath, a rice variety (Wissuwa *et al.*, 2002), and near isogenic lines to which this QTL was introgressed have significant yield in constrast to intolerant line nipponbare (Wissuwa, 2005). Yan *et al.* 1995 reported that legumes vary in their P use efficiency with respect to growth and yield. Genotypic variability has been found in common bean (*Phaselous vulgaris*) and pigeon pea (*Cajanus cajan*) regarding their ability to acquire P (Bonser *et al.*, 1996; Subbarao *et al.*, 1997).

Evaluations of cowpea lines have been conducted to explore potential genotypic variation for P uptake and P use efficiency. Mahamane *et al.* (2008) who screened 696 US Core collection and IITA accessions for adaptation to low soil P environments and for response to rock phosphate application found out significant differences in the cowpea lines ability to adjust to P stress deficiency and P acquisition from rock phosphate. Saidou *et al.* (2011) evaluated more than 100 cowpea accessions obtained from IITA, IAR, Zaria and INRAN on field and greenhouse conditions and reported wide genotypic variability among cowpea genotypes with regards to grain yield, P use efficiency and AMF infection rate as well as shoot-to-root ratio. A study conducted to assess P use efficiency and P uptake variability of 21 pigeon pea varieties using cowpea as control has indicated that pigeon pea and cowpea differ in P uptake strategies (Vesterager *et al.*, 2006). Their findings showed more accumulated P as well as more shoot and root in cowpea compared to pigeon pea. In another study, three groups of cowpea genotypes namely low, moderate and high, were obtained on the basis of Phosphorus Efficiency Index (PEI) (Kugblenu *et al.*, 2014). Genotypes with high PEI are IT03K-351-1, IT00K-901-5, IT93K-452-1 and IT98K-1263 while IT97K-819-118 has moderate and Soronko has the least. However, when the classification was made on the basis of PEI obtained from PCA and growth potential of shoot dry weight, nodule dry weight and P uptake efficiency at high P, IT93K-452-1, IT98K-1263 and IT03K-351-1 were detected as efficient and responders whereas IT97K-819-118 and Soronko were non efficient and poor responders to P application. Oladiran *et al.* (2012) screened 10 cowpea genotypes to determine their response to three levels of phosphorus and found out that the line IT97K-414-5 was the most efficient in P uptake. Similarly varietal variation with regard to P uptake from Gafsa rock phosphate was obtained when cowpea lines were assessed in a low P ultisol (Ankomah *et al.*, 1995).Two cowpea lines with high P use efficiency were also reported by Jemo *et al.* (2006). Saidou *et al.* (2007) evaluated cowpea accessions both in greenhouse and field conditions on three phosphate levels namely low P, RP and SSP. They reported lines tolerant to low P soil conditions but their performance appeared to be influenced by the environment. Some studies have surprisingly detected that seed size has an influence on P use efficiency in common bean and cowpea. Yan *et al.* (1995) observed that large-seeded *Phaseolous vulgaris* lines performed better on low P soils compared to small-seeded varieties. Ojo *et al.* (2007) reported that cowpea with large grain size have high P uptake than those with small seed size. They crossed IT90K-277-2, a cowpea line with high RP use efficiency and IT89KD-288 which responds negatively to RP to study the genetic basis of RP use efficiency. They noticed that backcross to each parent produces larger seed with more seed P and these backcrosses are more efficient in P uptake than either parent.

A study was conducted to examine the response of cowpea genotypes to sub-optimal P supply in alfisols of western Kenya by Gweyi-Onyango (2011). His findings showed that the cowpea line Elanda has greater P use efficiency than Inz since significant difference was detected in Elanda nodule weights but not in Inz under the P treatments (+ P and – P). However, the cowpea genotype Inzeku did not show any response to P application, its yield remains unchanged under + P and –P. Seven cowpea lines were evaluated for P uptake and P use efficiency under three P treatments (0 kg P, 30 kg P ha^{-1} as triple superphosphate (TSP) and 90 kg P ha^{-1} as Togo phosphate rock (PR) by Jemo *et al.* (2006) and significant variation was observed since nodule dry matter, shoot dry matter, grain yield, and P uptake differ significantly among the varieties tested. These authors also affirm that P application significantly augments N_2 fixation in cowpea. Eight varieties were screened in greenhouse under no P, low P and normal P treatments (Rothe *et al*., 2014). Each variety was uprooted at the onset of flower buds, dried overnight at 75°C and roots and shoot biomass weight were recorded. Among the tested varieties, Aloka and Danila were considered as susceptible because their shoot biomass was significantly inferior under low P compared to normal treatment, and their P susceptibility index (PSI) were higher than that of the tolerant varieties Big John, CB46, Golden eye, IT98K-476-8, and IT97K-1069-6.

A mapping population was developed using IT98K-476-8 (tolerant) and Aloka (susceptible) for the identification of QTL for low P tolerance (Rothe *et al*., 2014). 75 SSR markers that were polymorphic on the two parents were run on 120 F6 RILs progenies. The RIL shoot biomass data on low P treatment and the PSI obtained from both low and normal treatmebts were the phenotypic data used. Three SSR markers which are linked to low P tolerance in cowpea were identified from that study.

2.5.4. Mechanisms of adaptation to low P soils conditions

Plants require suitable climatic and soils conditions for adequate growth and development. However these environmental factors have been changing over time becoming more harsh and unfavorable for crop production as a result of natural happenings as well as human activities. Consequently, the rainfall is becoming low and erratic and the soils turn out to be deficient in organic matter and some essential mineral nutrients such as nitrogen, phosphorus and potassium. P which is a non-renewable element is among the crucial mineral nutrients deficient in Sub-Saharan Africa agricultural soils. Owing to the role it plays in crop development and yield, P deficiency in agricultural soils is a serious threat to food production. As a way of survival, some plant genotypes have developed mechanisms of adaptation to such conditions. Cowpea varieties that adapt well to low P soil conditions have been reported in literature. Adaptation mechanisms used by plants include root induced processes, root characteristics, mycorrhizal dependency, P uptake kinetics parameters, and rhizosphere processes (Nwoke *et al.*, 2005, Nielsen and Barber, 1978; Nielsen and Shjorring, 1983; Nye and Tinker, 1977, Nielsen, 1993).

2.5.4.1. Root induced processes

Inorganic phosphorus reacts with iron (Fe), aluminum (Al) and calcium (Ca) to become fixed, leading to P deficiency in soils. The secretion of organic acids and/or phosphatases and proton release that triggers the change in pH are among the mechanisms used by some plants genotypes to adapt to such conditions. Organic acids contained in root exudates have the ability to dissolve Ca, Fe and Al bound soil P (Dakora and Phillips 2002). Otani *et al.* (1996) observed that pigeon pea crude root exudates have more power in melting Fe and Al bound P than those of other crops, particularly at 4 and 5 weeks following transfer to the nutrient solution. They further noticed that more malonic, oxalic, and piscidic acid were released from pigeon pea roots compared to those of other crops. The exudation of organic acid from cowpea accessions tested on low P soils was investigated by Pypers *et al. (*2006). They reported increased exudation amount on low P soils without enhance P uptake due to the low concentration of P in the soil. Likewise organic acid production was determined on soybean and cowpea grown on low P soil by Nwoke *et al.* (2008). Their findings suggested that root length may be important since only citric acid known to have insignificant correlation with high P uptake in cowpea was detected. Mahamane *et al.* (2008) assessed the organic acid release of cowpea cultivars grown in hydroponic culture under P-deficient and P-sufficient conditions. Their results indicate that a tricarboxylic acid was the main organic acid secreted by cowpea roots that can be a piscidic acid which Ae *et al.* (1990) and Ishikawa *et al.* (2002) reported as the principal root exudates of pigeonpea. The quantity of organic acid released with P application is greater than that obtained without P (Mahamane *et al.*, 2008). This finding do not corroborate with the results of Rengel (2002), Dong *et al.* (2004), Hoffland (2006), and Pearse *et al.* (2007) who reported more organic acid secretion under P stress. Another study conducted on soybean by Liao *et al.* (2006) showed that citrate and oxalate exudation was stimulated by Al toxity and P deficiency respectively while malate secretion was triggered by both treatments.

2.5.4.2. Root morphology

Plants partially depend on mineral elements contained in the soils for growth and development. However these elements are not only unevenly distributed in the soils but they have also been depleted as a result of continuous cultivation, wind and water erosion as well as other natural causes and human activities. In such conditions the volume of soils exploited by the plant roots and root hairs may largely determine the amount of nutrients the plant can reach. The exhaustion of phosphate modifies the root system architecture to a large extent leading to superficial root system with more and elongated lateral roots as well as congested root hairs (Peret *et al.*, 2011). They further postulated that *Arabidopsis thaliana* copes with low P by decreasing primary root growth, improving lateral root formation and growth, and producing longer and more root hairs. Larger root system, root diameter and root hairs are very important root parameters that may play a paramount role in enhanced P uptake in plants. Larger root system results in more root-soil contact which is especially critical for P uptake (Gahoonia *et al.*, 2004). Root diameter determines the soil volume that can be exploited by roots when a given amount of photosynthate was invested (Atkinson, 1991). The geometrical arrangement of root hairs as well as its capability to amplify effective root surface area allow it to improve its efficiency to exploit rhizosphere soil for P (Gahoonia *et al.*, 1997). Root growth, root branching and root hair morphology are essential in order to take up P efficiently. Maize genotypes with high P efficiency have larger root systems, greater P uptake per unit root weight, more nodal roots, nodal root laterals, and greater root hair density of nodal root main axes and first-order laterals than did P inefficient accessions under P deficiency (Bayuelo-Jimenez *et al.*, 2013). Miguel *et al.* (2013) carry out a study to assess the correlation between the root traits variability and P uptake efficiency in common bean genotypes using radioactive phosphorus $_{32}$P. Their results revealed that lines with longer roots have high P uptake than those having short roots. However the exploitation of larger soil volume alone by plants may not confer to them high P uptake. Danila and IT82D-716 have low P uptake despite the exploitation of a relatively high soil volume by their roots and root hairs while IT89KD-349 exploited low volume of soil but pulls out more P (Krasilnikoff *et al.*, 2003). Similarly Kugblenu *et al.* (2014) found no correlation between cowpea root traits and grain yield per plant under low P in the field experiment.

2.5.4.3. Mycorrhizal dependency

The term ‘mycorrhiza’ is used to designate the relationship between certain non-pathogenic fungi and the roots of higher plants. Rhizobiums are in the soil, but they can only fixed N when they develop a symbiotic association with legumes. They enter the roots cortex by means of invagination and form an infection thread into the root hairs. They cause proliferation of cortical cells resulting in nodules formation on roots. The bacteria living in the nodules convert N into ammonia and make it available to plants for its growth. Dowdle *et al.* (1980) investigated the mycorrhiza inoculum levels in soils and quantified their contribution to the P nutrition of cowpea. Their results show that vesicular arbuscular mycorrhizae (VAM) improves P as well as Zn, S, K, and Sr uptake. It performs a crucial function in making P available to higher plants, especially in low P environment as it is in the tropics. Eighteen to 24 fold increase in pearl millet root and shoot dry matter was obtained through application of P without VAM treatment while the root and shoot dry matter of sorghum and cowpea relied on the interaction between P and VAM (Bagayoko *et* *al.*, 2000). Ngwene *et al.* (2010) investigated the interaction of AMF inoculation and the N03-: NH4+ ratio in making rock phosphate (RP) available to cowpea, but their results failed to provide any evidence that the combination of AM fungi and NO3- at neutal pH helps in making more RP available to plant. Similarly, a study conducted by Ahiabor and Hirata (2003) revealed that mycorrhizae (*Glomus etunicatum*) treatment did not have any impact on cowpea shoot dry weight whereas it has improved that of groundnut and pigeon pea; but the combine effect of rock phosphate, soluble phosphate and mycorrhizae has enhanced the cowpea total shoot dry matter production and the P content of its vegetative parts. These authors postulated that although the three inputs have acted synergically in improving the cowpea shoot dry weight, mycorrhizae had played a major role since it has not only stimulated additive sporulation responses on cowpea, but it has also increased root ramification in the soils allowing the plant to pull out more sparingly soluble P. Nutrients uptake of two cowpea varieties was enhanced by AM application under drought condition (Neumann and George, 2009).

2.5.4.4. Rhizosphere processes

Rhizosphere processes are among the important mechanisms that lead to mineral nutrients availability to plants especially in nutrient stressed environments. Roots secrete H+ or HCO3- (and CO2) that not only triggers pH change but also cause modifications in the redox potential. pH reduction promotes the melting of Ca bound phosphorus thus making more P available to plants. Proton release and organic acid exudation occur at the same time causing acidification of the rhizosphere to liberate sparingly soluble P for plant use (Mahamane *et al.* 2008). Latati *et al.* (2014) carried out a study to investigate if cowpea cultivation can make P more available in the rhizosphere to enhance the yield of cereals intercropped with legumes. Their results showed that cowpea cultivation as sole or intercropped with cereals improves the availability of P in the rhizosphere. Under low soil P level, increasing rhizoplane pH and citrate secretion in apical root zone of two cowpea varieties (Espace 10 and Santo Inacio) was observed to react to Al toxicity (Akinrinde *et al.*, 2007). Exploring the kinetics and mechanisms of cowpea root reaction to changes in calcium solution, Blamey *et al*. (2014) reported that roots respond to variation in Ca solution via impacts on cell wall relaxation of the rhizodermis and outer cortex in the elongation zone. Variation in adaptation to low P soils of three cowpea lines was investigated by Alkama *et al. (*2009) and they observed that the proton efflux for P-efficient genotype 26-73 was 43% and 60% greater than for the P-inefficient Danila in hydroaeroponics and in soil respectively, under P deficiency. They then inferred that the P use efficiency variation among the cowpea genotypes under inquiry depend on the nodulated-root proton efflux and respiration in the plant rhizosphere.

CHAPTER THREE

3.0. Evaluation of farmers knowledge, perceptions on low soil fertility and their cowpea varietal preferences

3.1. Introduction

Cowpea production in Niger is affected by many production constraints which include biotic and abiotic stresses. Low soil fertility was identified by farmers as one of the main abiotic factors causing serious threats to cowpea yield in the crop growing areas of Niger (SNV, 2008). The country is populated by over 17 million inhabitants composed up of about 90 % small scale farmers. Unfortunately only about 1/3 of the country's land area is suited to crop production; the arable land is therefore continuously cultivated without fallow since no new land is available. As a result, the soil nutrients are almost completely depleted as there is little or no organic matter since crop residues are used for feeding livestock as well as housing and nearly none is left on the field. In addition, chemical fertilizer's application is very low as the mean amount applied is about 1 kg/ha due to high cost, unavailability and poor income conditions of the farmers. Improper land use, overgrazing, deforestation, prolonged cultivation of the same field without suitable and required regulations bring about land degradation as well as soil nutrients depletion (Conant *et al.*, 2003; Kebede *et al.*, 2013; Bernoux *et al.,* 1998). Farmers' actions contribute to a large extent in the loss of agricultural soils nutrients and acquaintance with their perceptions about soil fertility may be a key factor in designing agricultural soil management strategies. All the actors involved in the protection of soils used for cropping can gain from taking into account local knowledge and farmers' vision with respect to soil fertility (Marenya *et al*, 2008). Farmers' awareness of various soil types and its management as well as their ability to assist researchers in soils classification has been reported in many studies (Tabor, 1992; Pawluk *et al.*, 1992; Hecht, 1990).

Farmers use soil color, texture, depth, topograghy, drainage and farm distance from home to determine soil fertility (Corbeels *et al.*, 2000; Yeshaneh, 2015). Other indicators of soil fertility according to growers are reduction in crop yield, weed infestation, rocky outcrop, early plant wilting in the growing cycle (Corbeels *et al.*, 2000; Bizabih *et al.*, 2016; Mahler *et al.*, 2015, Marenya *et al.*, 2008) and soil erosion (Kediro, 2015). The emergence of striga in a field is viewed as a sign of low soil fertility by farmers in some areas of Niger (Salifou *et al.*, 2015). Also Zouera *et al*. (2016) associated infestation of a field by striga with poor soil fertility.

Farmers' assessment of soil fertility is subjective as it is based on observations and does not involve any scientific test. The combination of farmers' assessments with the ones obtained from soil laboratories may give an insight on soil fertility status. Authors have called for finding the correlation between indigenous and scientific soil knowledge for sustainable management of agricultural land resources (WinklerPrins, 1999; Sherwood and Uphoff, 2000). An agreement was detected between the physicochemical analysis and farmers' assessment of soil fertility (Yeshaneh, 2015). Also, Marenya *et al.* (2008), using a univariate regression without controlling covariates, observed a strong significant positive correlation between farmers' soil fertility perception and percent soil carbon content; however when the yield is controlled, the relationship becomes non significant.

Many technological packages with respect to cropping systems, integrated soil management and improved crop varieties have been developed and disseminated to farmers; however their adoption rate remains very low. In developing countries, small scale farmers, especially in rural areas do not generally readily adopt innovations. Some farmers believe that they are experts in agriculture due to the possession of indigenous knowledge. With regard to crop cultivars, farmers have selected their own varieties, the landraces, which are adapted to their social, economic and environmental conditions as well. Witcombe *et al*. (1996) stated that farmers of marginal areas in most developing countries keep using landraces since improved varieties which performed better than theirs were not widely disseminated to them. But low adoption may also occur if the new variety is not adapted to farmers' conditions and perception. Almekinders and Louwaars (1999) hypothesized that collaboration with farmers' right from the stage of goals' setting, up to the selection of varieties can foster adoption. However, the conventional breeding top-down decision-making and information flows, where the views of farmers and other stakeholders are not sufficiently considered in varietal development has caused low adoption rate of improved crop cultivars. The conventional package of new varieties and external inputs, although efficient under good environment, did not generally improve the livelihood of farmers in rural areas (Ceccarelli *et al*, 2009). Participatory plant breeding (PPT) and participatory varietal selection (PVS) have evolved to address the problem of low adoption rate of improved of crop varieties. Ashby (2009) stated that several investigations inferred that PPB and PVS increase farmers'adoption of formally bred cultivars in marginal areas since these approaches take into account their needs in developing, testing and release of varieties. In cowpea, like any other crop, farmers' preferences with respect to varieties vary from one region to another. The important cowpea varietal traits include yield (grain and fodder), phenological cycle, tolerance to biotic and abiotic constraints, seed size, seed color and market value. Usually, farmers go for large white or brown seeds with rough coat in West Africa (Nielson *et al.*, 1993). However, grain yield has always been among the important traits to farmers with respect to cowpea varieties, but nowadays, with the shortening of rainy seasons in Niger caused by climate change, cowpea growers living in the dry areas have abandoned their landraces which are late maturing, high yielding for both grain and fodder and started requesting for extra early varieties. Resource-poor farmers do not have enough means to invest in agricultural inputs such as fertilizers and insecticides, as a result they ask for varieties that can give acceptable yield under biotic or abiotic stresses with no or minimum added inputs. In Niger, cowpea is presently the most important cash legume and farmers have started paying attention to its market value. Preferences of cowpea growers in some localities of the country have been determined through PRA (Salifou *et al*, 2015) and it turns out that high yield potential, early maturity, white seed color and good taste are the most preferred traits. It is however necessary to determine farmers' cowpea varieties preferences in all major cowpea growing areas in order to make specific recommendations for each locality. Hence, the present study was carried out to:

- assess farmers' knowledge and perception of low soil fertility and its effect on cowpea production;

- determine farmers' preferences regarding cowpea varieties.

3.2. Materials and methods

3.2 1. Site selection

The survey was conducted in the 3 major cowpea growing areas of the country which are Dosso, Maradi and Zinder. In each region, 3 departments were selected on the basis of the importance of cowpea production as well as soil fertility problem. A total of nine departments namely Birni Ngaoure, Loga, Doutchi in Dosso , Guidan Roumdji, Dakoro, Mayahi in Maradi, Matameye, Magaria and Goure in Zinder were selected for the present study. Three villages were sampled per department. However, only two villages were selected in Birnin Ngaoure as well as in Loga as a result of some constraints. The present survey was carried out in 25 villages which were selected on the basis of informations received from extension services.

3.2.2 Sampling method

In each village, household heads were gathered at the chief's house. Random sampling method namely ballot papers were used to select respondents among household heads present at the meeting. Two hundred and fifty (250) respondents (Table 3.1), 10 in each village, were interviewed. Data on cowpea production, soil fertility knowledge and perception and other production constraints were collected per farm and every respondent was allowed to give information of a maximum of five farms. In each household, data were collected on female farm when available to take into account gender aspect.

Table 3.1 Number of respondents per region

Region	Number	Percentage (%)
Dosso	70	28.00
Maradi	90	36.00
Zinder	90	36.00
Total	250	100.00

3. 2. 3 Interview guides and data collection

Structured, semi-structured questionnaires as well as ranking were the materials used for data collection. While the structured questionnaire was administered to individual household heads, the semi-structured questionnaire and ranking were used in the focus group discussion (FGD). One FGD was organized per village; this approach was used to get general information about agriculture in each area and to list and rank cowpea production constraints. In the case of household questionnaire, data was collected electronically with the help of tablets on which CS Entry 6.1 software was installed, the questionnaire was than uploaded to the tablets. Data were collected on the socio-economic characteristics of respondents, soil nature and constraints to cowpea production.

3. 2.4 Data analysis

The data analysis which consists of descriptive statistics and ranking was carried out using Stata 14 software.

3.3. Results

3.3.1. Socio-economic characteristics of respondents

The age of respondents ranged from 17 to 90 years. The mean age of respondents across the study areas was 42.56 years. Household heads in Zinder were slightly younger compared to those of Dosso and Maradi. The mean age was 44.23 years for Dosso, 43.23 years for Maradi and 40.17 years for Zinder (Table 3.2).

Table 3.2 Average age of respondents (years)

Region	**Mean**	**Range**
Dosso (n=70)	43.27	55
Maradi (n=90)	44.23	72
Zinder (n=90)	40.17	58
Total (n=250)	42.56	73

With regard to education, the results showed that 72.4% of interviewees had not been to school revealing the low level of formal education in these areas, 17.2 % of respondents had primary education while 9.2 % had secondary (Table 3.3). Formal education was slightly higher in Zinder compared to the other two regions. Most of the respondents who went to school dropped out from primary level.

Table 3.3 Formal Education levels of respondents

	Region							
	Dosso		**Maradi**		**Zinder**		**Total**	
LEVEL OF EDUCATION	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
None	53	75.71	67	74.44	61	67.78	181	72.40
Primary	14	20.00	13	14.44	16	17.78	43	17.20
Secondary	3	4.29	9	10.00	11	12.22	23	9.20
Tertiary	0	0.00	1	1.11	2	2.22	3	1.20

The principal occupation of most of the respondents was agriculture. The most important secondary occupations were small business and livestock rearing.

3.3.2. Farms and soils

The number of farms per household varied from one to more than five among respondents. Most farms, 71.33 % are located far from homes while 28.1 % of them were very close to villages. The number of backyard farms was significantly lower in Dosso compared to the two other regions (Table 3.4).

Table 3.4 Distance of farms from villages

	Region			
Farms	**Dosso (n=70)**	**Maradi (n=90)**	**Zinder (n=90)**	**Total (n=250)**
Back yard	19.15	30.75	32.41	28.10
Far from villages	80.75	69.25	67.59	71.87

The mode of acquisition of farms include inheritance, purchasing, gift, borrowing and hiring. However the most important mode was inheritance as its proportion across the study area amounted to 82.23 %. Higher number of respondents inherited their farms in Dosso and Zinder compared to Maradi. The most important mode of farm acquisition after inheritance were purchasing and borrowing with 7.65 and 7.10 % respectively. The proportion of respondents who purchased their farms was greater in Maradi in comparison to Dosso and Zinder. Farm hiring was done mainly in Maradi region. Borrowing was however higher in Dosso and Zinder compared to Maradi. Very few of respondents received their farms from government (Table 3.5).

Table 3.5 Mode of farm acquisition

Mode of acquisition	**Region**			
	Dosso (n=70)	**Maradi (n=90)**	**Zinder (n=90)**	**Total (n=250)**
Inheritance	87.85	74.66	85.42	82.23
Purchase	1.36	15.10	5.09	7.65
Received from Government	0.92	0.56	1.11	0.86
Borrow	9.46	4.45	7.92	7.10
Hire	0.41	5.64	0.46	2.16

Farms usually belong to household heads. However, in every household, women possessed small plots of lands obtained from their families or borrowed/gifted by their husbands. The management of women farms was carried out mainly by men, who are most often their husbands, sons or brothers. The present study showed that only about 4 % of women farms were managed by women themselves.

Farmers classified soils as sand, clay and sand-clay. Across the study areas, 68.22 % of respondents claimed that the soils of their farms are made up of sand while those who described their farms soil as sandy-clay and clay were 18.62 and 3.95 % respectively. According to the results, the proportion of sandy soils was higher in Zinder than Maradi and Dosso while that of sandy-clay was high in Dosso (Table 3.6).

Table 3.6 Soil texture according to farmers in the study areas

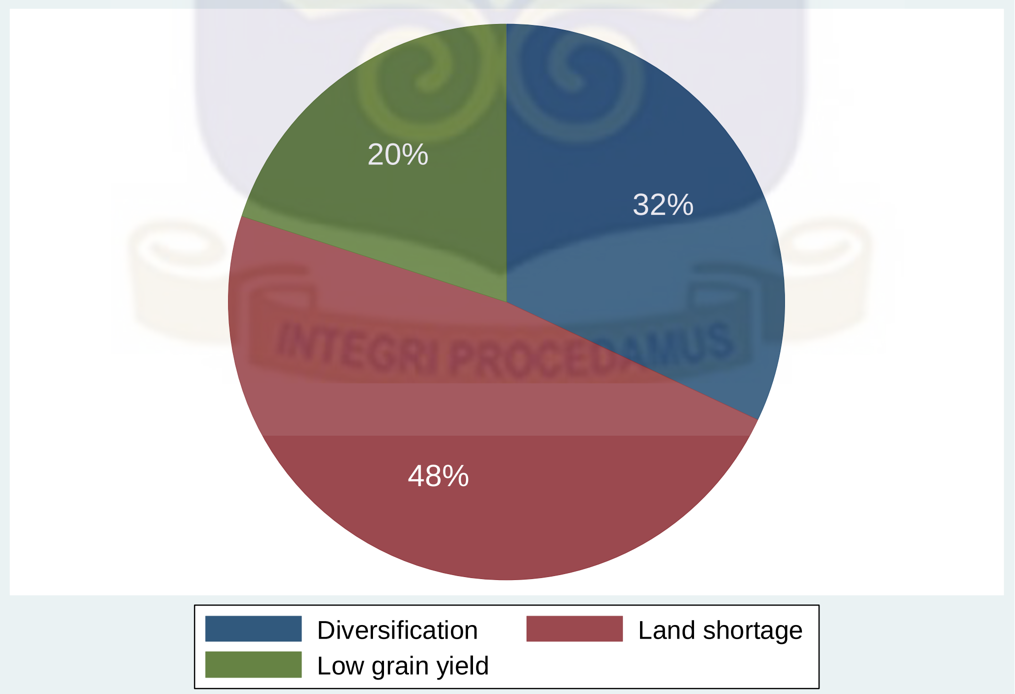
	Region			
Soil type	**Dosso (n=70)**	**Maradi (n=90)**	**Zinder (n=90)**	**Total (n=250)**
Sand	53.26	67.13	80.93	68.22
Clay	2.57	5.93	3.04	3.95
Sandy-clay	22.94	21.15	12.73	18.62
NA	20.23	5.78	3.29	9.21

NA = proportion of farmers who were able not to give information about the soil texture of their farms.

3.3.3. Cropping systems

More than 20 different crops were grown by farmers of the surveyed areas. It includes millet, cowpea, sorghum, groundnut, Bambara nut, sorrel, okra, maize, cassava, sweet potato, tomato, tiger nut, sesame, watermelon. However, the most important and widely cultivated crops were millet, cowpea, sorghum and groundnut.

Millet and cowpea were the only crops that adapt to almost all agro-ecological zones of the country. Cowpea was mainly grown in association with millet according the findings of the present study. During the focus group discussion (FGD), in 18 of the 25 villages where the PRA was conducted, farmers affirmed that cowpea was mostly cultivated in association with millet. According to them, mixed cropping is a way of adaptation to shortage of land but it also helps in reducing the risk of total production loss because of its diversification nature. Although mixed cropping was the main cropping system, improved varieties were cultivated in sole cropping since they do not give high grain yield in mixed cropping (Fig. 3.1).



PRA survey, 2015)

Figure 3-1 Farmers’ reasons for growing cowpea in association with millet and other crops

The results of the FGD showed that both local and improved varieties of cowpea were used in 88 % of the sampled villages while in 12 % of the villages, only local varieties were cultivated. Farmers who grow cowpea in sole cropping system were either improved seeds key distributors and/or those who participated in the demonstration programs or attended capacity building workshops organized by extension services and non-governmental organizations (NGO).

3. 3. 4. Farm size

Wide range was observed in terms of farm size among respondents. Farm area per household varied from 0.5 to 53, 0.7 to 54 and 0.3 to 16 ha in Dosso, Maradi and Zinder respectively. The mean farm size per household is 5.58 ha varying from 3.23 to 7.24 across the study area. Our results showed that households in Zinder have significantly less farm land compared to Maradi and Dosso (Table 3.7).

3.3.5. Cowpea production and yield

The production and the yield of cowpea reported in the present work concerned only the cropping season of year 2014. The mean production per household ranged from 0 to 2750 kg with a mean of 223.69 kg per household. The mean yield was 59.5 kg/ha and varied from 0 to 870 kg/ha. There were variation among the three regions with regard to both production and yield. Both the production and the yield were higher in Dosso in comparison to the two other regions. The lowest production was observed in Zinder while the lowest yield was recorded in Maradi. Farmers claimed that 2014 was a bad cropping season. They also asserted that the production of cowpea was generally low in recent years; however the production in a normal year is usually higher than that of the 2014. The results suggested that cowpea performed better in Dosso in comparison with the two other regions (Table 3.7)

Table 3.7 Area (ha), production (kg), and yield (kg/ha) of cowpea

Region	Area (ha)		Production (kg)		Yield (kg/ha)		
	Mean	Range	Mean	Range	Min	Mean	Range
Dosso (n=70)	6.47	52.5	331.11	2750.00		79.82	870.00
Maradi (n=90)	7.24	53.3	234.97	2000.00		36.80	166.67
Zinder (n=90)	3.23	15.7	128.85	750.00		66.44	330.77
Mean (n=250)	5.58	53.7	223.69	2750.00		59.52	870.00

Farmers may have some difficulties to adequately estimate yield, they can however easily judge the production. According to majority of them (75.63%), the 2014 cowpea production was low, however 22.11 % affirmed that it was average while only 2.26 % viewed it as good (Table 3.8)

Table 3.8 Farmers assessment of their year 2014 cowpea production

Evaluation of the production	Region			
	Dosso (n=70)	Maradi (n=90)	Zinder (n=90)	Total (n=250)
Low	77.84	66.49	83.06	75.63
Medium	21.12	29.85	15.13	22.11
Good	1.04	3.66	1.81	2.26

3.3.6. Production constraints

Many production constraints were faced by cowpea growers; the most serious ones which often cause economic yield loss were drought, insects, poor soil fertility, striga, diseases and poor seed quality. The rankings obtained from the focus group discussion showed that drought is the predominant constraint impeding cowpea production in the study areas; it is followed by low soil fertility. Taking into account the overall ranking, other major problems include insects, diseases, poor seed quality and striga (Table 3.9.).

Table 3.9 Ranking of cowpea production constraints by farmers during FGD

Constraints	Score1	Score2	Score3	Score4	Score5
Drought	72.0	4.4	-	4.2	5.0
Low soil fertility	12.0	34.8	13.7	4.2	25.0
Insects	4.0	30.4	50.0	16.7	25.0
Poor seed quality	4.0	13.0	18.2	33.3	20.0
Striga	4.0	-	4.5	16.7	20.0
Diseases	4.0	-	-	-	-
Birds	-	-	-	4.1	-
Others	-	17.4	13.6	20.8	-
TOTAL	**100**	**100**	**100**	**100**	**100**

Like the FGDs, the results of household questionnaire revealed that farmers were aware of soil fertility problem. The results showed that low soil fertility was the major constraint to cowpea production as it recorded the highest mean percentage of 69.91 % across the survey areas. Other factors that cause sizeable reduction in cowpea production were low rainfall, insect pests and poor field management. The results showed that low rainfall impact on cowpea production was higher in Zinder compared to Maradi and Dosso (Table 3.10).

Table 3.10 Farmers reasons for low cowpea production

	Region			
Reasons	**Dosso (n=63)**	**Maradi (n=78)**	**Zinder (n=85)**	**Total (n=226)**
Low rainfall	9.52	28.21	48.24	30.53
Rainfall distribution	1.59	1.28	4.71	2.65
Flood	1.59	0.00	0.00	0.44
Wind	0.00	0.00	1.18	0.44
Bird	0.00	1.28	0.00	0.44
Insect	4.76	1.28	10.59	5.75
Rodents	0.00	1.28	1.18	0.88
Livestock	1.59	2.56	0.00	1.33
Late onset of rains	3.17	11.54	2.35	5.75
Late weeding	6.35	6.41	0.00	3.98
Poor Field management	9.52	3.85	3.53	5.31
Low soil fertility	87.30	73.08	54.12	69.91
Farm far from village	0.00	0.00	1.18	0.44

While assessing the fertility status of their farms, 48.87 % of the respondents claimed that their field soils are poor, the farms are even very poor according to 11.29 % of interviewees. However 39.48 % of interviewed household heads believed that their fields are fertile. The proportion of poor soils was higher in Dosso and Zinder compared to Maradi (Table 3.11).

Table 3.11 Assessment of the fertility status of farms by respondents

	Region			
Perception on soil Fertility	**Dosso (n=70)**	**Maradi (n=90)**	**Zinder (n=90)**	**Total (n=250)**
fertile	32.61	43.97	41.33	39.84
Poor	52.67	43.38	51.41	48.87
Very poor	14.72	12.65	7.26	11.29

Soil erosion is among the factors that bring about the problem of soil fertility. Over 77% of the agricultural soils were eroded according to respondents; about 14% of respondents claimed their soils are even much eroded. Only 9 % of the respondents stated that the soils are not eroded (Table 3.12).

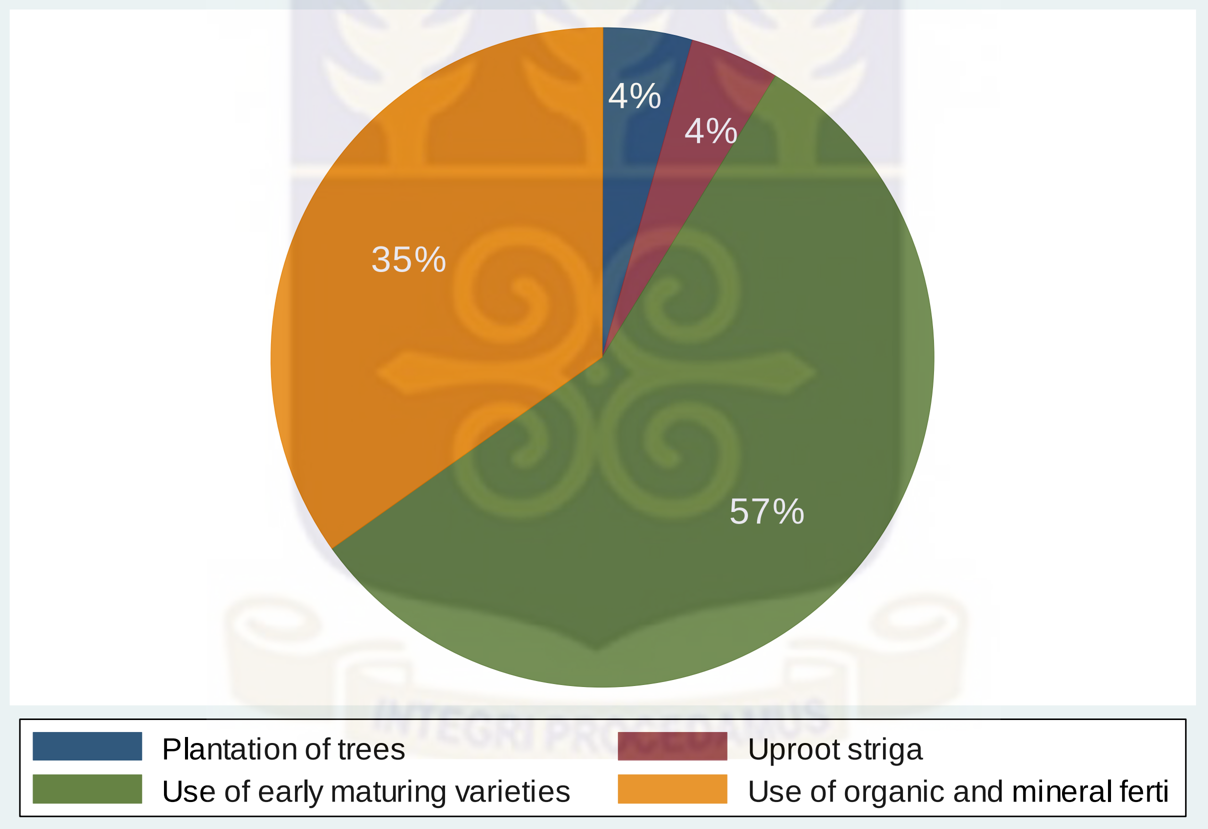
Table 3.12 Erosion level of farms according to respondents

	Region			
Perception on soil Erosion	**Dosso (n=70)**	**Maradi (n=90)**	**Zinder (n=90)**	**Total (n=250)**
No eroded	12.93	11.78	3.27	9.04
Eroded	75.41	70.57	85.48	77.29
Very eroded	11.67	17.65	11.25	13.67

3.3.7. Management of production constraints by farmers

Farmers have devised their own ways of dealing with production constraints. To reduce the impact of drought, they used early maturing varieties although this alternative works only in the case of terminal drought. Some farmers planted trees, left crop residues on the field, or/and applied organic and inorganic fertilizer (usually NPK, Urea and DAP) to handle the problem of soil fertility deterioration (Fig. 3.2 and Table 3.13). The overall proportion of respondents that applied fertilizers were 40%; those who used manure, pesticides and improved seeds were 76.8 %, 10 % and 32 % respectively. Among the inputs, manure is the most utilized by respondents. In contrast the use of pesticides was very low. The utilization of improved varieties as revealed by the results was relatively high (32.80 %). The use of agricultural inputs was higher in Maradi in comparison to Dosso and Zinder.

Striga was however manually uprooted. With respect to erosion some respondents said that they leave millet straw in order to protect the soil from such degradation. Other more efficient technologies such as wind breaks and stone bunds/lines transferred by extension services, development projects and NGOs were used by some farmers.



Source: PRA survey, 2015)

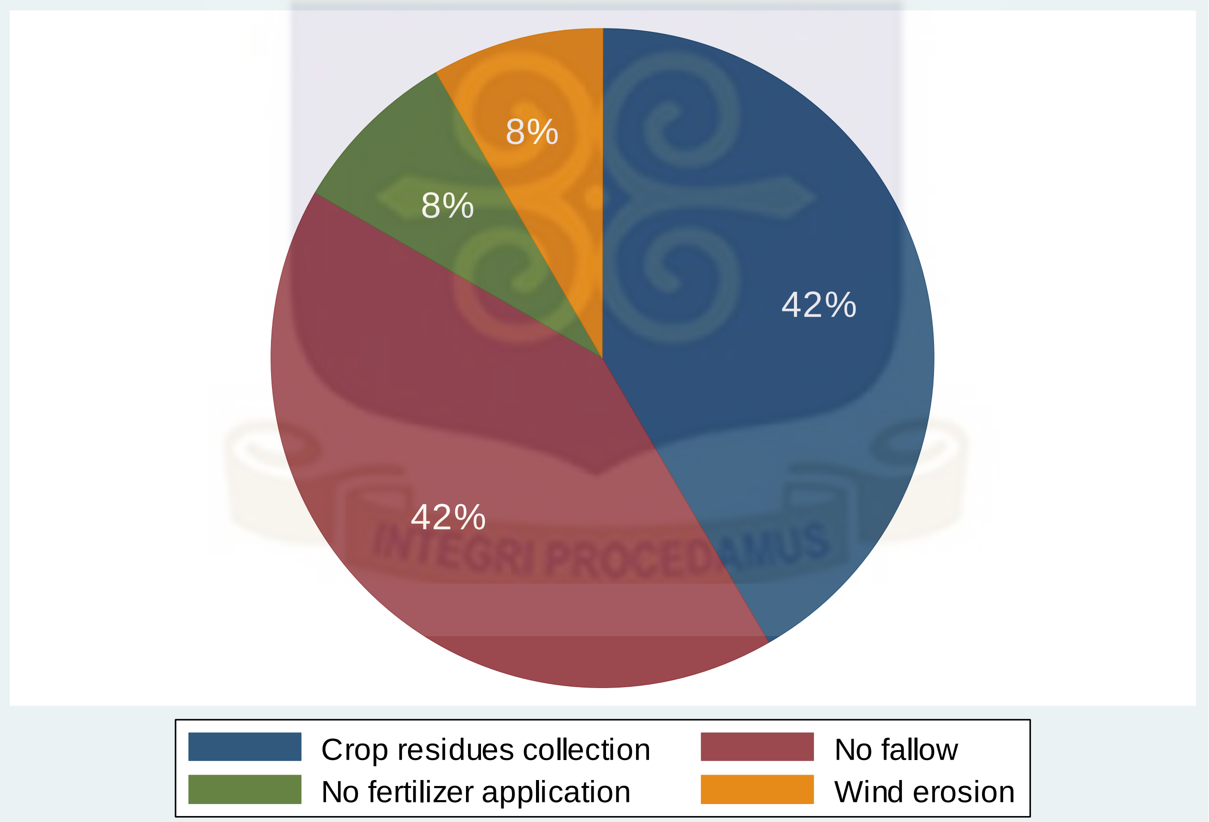
Figure 3-2 Management of production constraints by farmers (FGD)

Table 3.13 Use of agricultural inputs by farmers (Questionnaire)

	Region			
Inputs type	**Dosso (n=70)**	**Maradi (n=90)**	**Zinder (n=90)**	**Total (n=250)**
Fertilizer	70.00	42.22	14.44	40.00
Manure	75.71	75.56	78.89	76.80
Pesticides	8.57	16.67	4.44	10.00
Cowpea improved variety	28.57	43.33	25.56	32.80

3.3.8. Causes of soil fertility deterioration

According to the focus group discussion results, the factors that contributed to soil fertility deterioration include collection of crop residues from farms, lack of fallow or reduction in its duration, wind erosion and lack of fertilizer application. However, collection of crop residues from fields and lack of fallow were the main causes of reduction in soil fertility (Fig. 3.3).



Source: PRA survey, 2015)

Figure 3-3 Factors causing reduction of soil fertility according to farmers

3. 3.9. Farmers varietal preferences

Early maturity and high grain yield potential were the traits preferred by farmers in terms of cowpea variety. Early maturity had a mean score of 2.35 while high grain yield recorded a mean of 2.40 across the study areas. Furthermore a median of 1 and 2 were recorded by early maturity and high grain yield respectively, meaning that at least 50 % of respondents ranked early maturity as first preferred traits and high yield as second (Table 3.14). By giving preference to high grain yield, farmers expressed their preferences for drought, low soil fertility and insect pest tolerance. The remaining traits that include seed size, seed weight, seed coat color, taste, cooking time and market value were of low importance to respondents according to the results of the present work.

Table 3.14 Ranking of variety traits by farmers

	Region							
	Dosso (n=70)		**Maradi (n=90)**		**Zinder (n=90)**		**Total (n=250)**	
Traits	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**	**Mean**	**Median**
Grain size	3.86	5.00	4.10	5.00	4.92	5.00	4.33	5.00
Grain color	4.56	5.00	4.68	5.00	4.91	5.00	4.73	5.00
Grain weight	4.49	5.00	4.80	5.00	4.81	5.00	4.72	5.00
Grain yield	2.86	3.00	2.02	2.00	2.43	2.00	2.40	2.00
Fodder yield	4.29	5.00	4.42	5.00	4.70	5.00	4.48	5.00
Drought tolerance	4.94	5.00	4.09	4.00	3.44	3.00	4.10	4.00
Field Insect tolerance	4.63	5.00	4.64	5.00	4.09	4.00	4.44	5.00
Striga tolerance	4.96	5.00	4.87	5.00	4.91	5.00	4.91	5.00
Poor soil tolerance	4.89	5.00	4.90	5.00	4.78	5.00	4.85	5.00
Early maturity	3.59	5.00	2.48	2.00	1.27	1.00	2.35	1.00
Dual purpose	4.91	5.00	4.61	5.00	4.91	5.00	4.80	5.00
Taste	3.57	4.00	4.90	5.00	4.96	5.00	4.55	5.00
Cooking time	4.97	5.00	5.00	5.00	5.00	5.00	4.99	5.00
Market value	4.64	5.00	4.60	5.00	4.96	5.00	4.74	5.00
Store insect tolerance	3.94	5.00	5.00	5.00	4.91	5.00	4.67	5.00

Early maturing varieties were preferred in Zinder and Maradi, however in Dosso at least 50 % of respondents gave it a rank of 5 which is the last rank. The preference of high yielding varieties cut across all the study areas. Respondents of Maradi and Zinder stated three reasons for preferring early maturing varieties:

- Rainy seasons were becoming shorter from one year to another, rainfall hardly goes beyond 2.5 months, so they need varieties that can mature before the rains stopped;
- Shortage of food occurred almost every year from the middle of the cropping season, farmers who planted early maturing varieties can get food from their farms earlier and this allowed them to stay on their farms and carry out remaining farm operations;
- Towards the end of the rainy season, the price of feedstuffs, especially cowpea, is high on local markets, the earlier the harvest, the more likely to take advantage of the good price.

3.4. Discussions

The low level of formal education among respondents reported in the present work corroborated with Republique du Niger, (2001) where it was reported that illiteracy rate among adults in rural areas is 83 %. Education rate in rural areas started rising only in the year 2000 when the government adopted mass education policies. The very poor level of education of respondents revealed by this study is partly due to the fact that young men, especially those with some level of formal education do not have any interest in agriculture and have therefore migrated from the rural to urban areas.

The use of improved cowpea varieties along with local cultivars in 18 of the 25 surveyed villages may be attributed to the promotion of “community seed growers” among the farmers by extension services; emergence of private seed companies as well as the establishment of input shops in rural areas. However, most of the released improved varieties were not adopted by farmers; only few improved varieties namely IT90K-372-1-2, KVX-30-309-6G, TN5-78, IT97K499-38, IT97K499-35 and IT99K-573-1-1 were widely used by growers from the eighteen improved varieties published in the national catalogue of plant species and varieties.

The cultivation of cowpea in association with millet by majority of our respondents across the nine districts where the survey was conducted is in agreement with the findings of Salifou *et al*. (2015) who reported that cowpea was mainly intercropped with millet and sorghum in three districts of Niger. It also corroborated with Langyintuo *et al*. (2003) who found that cowpea was mostly planted in association with millet and sorghum in West and Central Africa. The mean cowpea yield of 59.5 kg/ha reported in the present work was an indication of vey low cowpea yield in farmers field. It was below the range reported in the national statistics where it is stated that cowpea yield in Niger ranged from 68 to 388 kg/ha with a mean of 208 kg/ha from 2000 to 2012 INS (2013). Although the yield remains low, there was an increase in cowpea production in Niger in recent years as a result of expansion of area under cultivation since the crop progressively occupied most of the areas allocated to cash crops, especially legumes. The very low production of cowpea in 2014 revealed by the current study was not consistent with FAOSTAT (2014) where it was reported that 2014 cowpea production in Niger was higher compared to 2013.

However, the trends of both production and yield followed an uneven development (zigzag pattern) from one year to another depending on the incidence of one or more major production constraints. The identification of drought and low soil fertility as most important production constraints in the present work was consistent with previous findings in many cowpea producing countries. In Niger, drought, insects, striga, low soil fertility were among the top constraints to cowpea production (SNV, 2008). Similar results were reported by Asante *et al*. (2001) and Egbadzor *et al.* (2013) in Ghana, Tignegre, (2010) in Burkina and Adipala *et al*. (2000) in Uganda. The claim by farmers that striga was associated with low fertile soils is in agreement with Salifou *et al.* (2015). It also corroborated with Zouera *et al.*

(2016) who declared that soils infested by striga were significantly poorer than those that were not. Hence the spread of striga in agricultural soils of Niger may support the hypothesis that low soil fertility is a widely spread problem in agricultural soils of Niger with its subsequent setbacks to crop production. Agricultural soils of Niger, especially those of upland are deficient in essential nutrients required for optimal plant growth. They contain on average 0.1 to 0.7% soil organic matter, a pH of 4.5 to 6.0, Bray-1 P of 0.4 to 3.4 mg/kg of soil and low available N (Nouri *et al*., 2017). Low P content in soils, causes stunted growth, delays in flowering and pod setting leading therefore to poor grain and fodder yield.

In the present study, farmers were able to assess the fertility status of their farms although their assessment may be subjective since not based on any scientific test. According to Corbeels *et al*, (2000) and Yeshaneh, (2015), farmers determine soil fertility on the basis of soil color, texture, depth, topography, drainage and farm distance from home. Their findings agreed to some extent with the results of the current study since the respondents believed that back yard farms are richer than those located far from villages because the village waste was dumped on it. However with regards to soil texture, the interviewees could only identify sand, clay and sand-clay soil texture types. They believed that clay soils are more fertile than sandy soils as they grew crops that they think are more demanding in terms of nutrients such as sorghum on clay soils while millet and cowpea were mostly cultivated on upland sandy soils. The predominantly sandy texture of soils in the study areas revealed by the results was consistent with Republique du Niger, (2001) where it was reported that agricultural soils of Niger have a sand proportion varying from 80 to 90 %, 1 to 8 % of clay and 2 to 6 % of silt. The respondents' beliefs that fertile soils gave higher production compared to poor soils was consistent with Mahler *et al.*, (2015) who reported that low crop yield is an indicator of poor soil fertility to farmers.

Before the advent of crop research in the sub-Saharan African countries, farmers used to choose varieties through mass selection. In the selection of these cultivars called “landraces”, farmers make use of their own criteria that may not tally with those of formal plant breeders. Usually farmers select varieties that are adapted to their agro-ecological environments and to their socio-cultural needs and economic conditions. The results of the present study showed that the two most important traits preferred by farmers with respect to cowpea varieties were early maturity and high grain yield potential. Similar results were obtained by Salifou *et al.* (2015) in Niger, Ansah *et al.* (2014) in Ghana and Orawu (2007) in Uganda. Early maturating varieties were prioritized by farmers in order to avoid yield loss caused by terminal drought since the rainy season is becoming shorter as a result of climate change. However early maturity alone may not be enough to prevent the negative impact of drought on cowpea production, seedling drought tolerance is necessary as rain distribution within the season is most often erratic especially in the beginning of the season, early maturity should therefore be accompanied with tolerance to seedling drought in order to obtain good harvest. The strong correlation between seedling and terminal drought tolerance in cowpea reported by Watanabe *et al.* (1997) was crucial information to breeders for the development of drought tolerant cultivars of cowpea.

The fact that seed size and seed coat color were not cited among the important traits by our respondents was not consistent with many findings as large seed size and white coat color were reported as farmers preferred traits by Kormawa *et al.* (2000) in Nigeria, Salifou *et al.* 2015 in Niger, Tignegre, (2010) in Burkina, Egbadzor *et al.* (2013) in Ghana and Langyintuo *et al.* (2003) in the whole West and Central Africa. Large seed size was preferred by consumers in Niger according to Ibro *et al.* (2011) who studied the effects of physical and chemical characteristics of cowpea on its price in Niger. They further stated that consumers in Niamey were ready to pay more to get brown seed cowpea. Cowpea is presently the most important cash legume crop in Niger; however, only the respondents of Gouré, a department located in the eastern part of Zinder region talked about its market value, they claimed that brown coat seeded cowpea have higher price on the market of Kano (Nigeria) than varieties with white seed color. Ibro *et al.* (2011) also reported that brown seeded cowpea produced in Zinder was exported to Nigeria; as a result, white seeds were dominant on markets of Zinder, as well as Maradi and Niamey.

3.5. Conclusion

In the present work, farmers have identified drought and low soil fertility as the most critical constraints to cowpea production in their various communities. They are aware that their soils are poor and they know that low fertile soils impact negatively on cowpea production. Early maturity and high yield potential are the preferred traits with regard to cowpea varieties. However low soil fertility, especially low levels of P not only leads to low yield, but also delays flower and pod setting in cowpea. Therefore, farmers are left with only two options: it is either to apply fertilizer (inorganic or organic) or to grow tolerant varieties. Owing to the high price as well as low availability of fertilizers in rural markets and the extremely low income condition of small scale farmers in Niger, the best alternative is to use varieties that are tolerant to low P. With the objective of identifying and/or developing cowpea varieties tolerant to low P soil conditions, this thesis research is thus a welcome development.

CHAPTER FOUR

4.0. Genetic variability and heritability of cowpea traits under low P soil conditions

4.1. Introduction

In Niger, poor soil fertility, especially low phosphorus, is one of the serious problems dwindling cowpea production and yield as well. The use of fertilizers and/or organic manure in order to solve the problem is impeded by farmers' socio-economic conditions as well as poor availability and high price of mineral fertilizers on local markets. The cheap and environmental friendly alternative is the development of cultivars with high grain and fodder yield under low soil P conditions.

However the successful development of elite cultivars depends on the crop germplasm diversity (Baudoin and Maréchal 1985). Although cowpea is a self-pollinating crop species, there is a large variation in its wild as well as cultivated germsplam that can be explored in breeding through genetic manipulations (Ng and Maréchal, 1985) for the development of better performing varieties. Breeders have made considerable progress in cowpea breeding by exploiting the crop's genetic diversity through the use of both phenotypic and genetic markers in the identification of sources of genes for tolerance/resistance to various abiotic and biotic stresses. Significant genetic variability have been reported for traits associated with resistance/tolerance to drought (Fatokun *et al*., 2012, Mafakheri *et al*., 2017), striga (Kamara *et al*., 2008; Omoigui *et al*., 2007; Tchiagam *et al*., 2010), aphids (Souleymane *et al*., 2013) and low P (Mahamane *et al*., 2008; Vesterager *et al*., 2006; Krasilnikoff *et al*., 2003; Oladiran *et al*., 2012; Alkama *et al*., 2009; Jemo *et al*., 2006; Saidou *et al*., 2007; Ojo *et al*., 2007) .

Selection of superior genotypes requires not only large variation in the germplasm with regard to the traits under consideration, but also high heritability. Omoigui *et al*. (2006) reported a moderate-to-large genetic variance and heritability in some cowpea reproductive traits. They also noted substantial genetic variability regarding shoot weight, 100-seed weight, days to flowering and plant height. The same authors noted high heritability estimates for 100-seed weight, duration of reproductive phase, days to first flower appearance, maturity, and harvest index. Similarly, Gerrano *et al.* (2015) collected data on 16 phenotypic traits while screening 25 cowpea cultivars in South Africa and observed large significant differences for all the traits; however they noticed that phenotypic variance is larger in comparison to genetic variance with respect to all quantitative traits. They also reported high heritability for all the traits except for the number of branches. Several other authors including Inuwa *et al*.(2012); Animasaun *et al*. (2015), Ajayi *et al*. (2014); Damarany, (1994); Nwosu *et al*. (2013); Fonji *et al*. (2015); Dias *et al*. (2016); Ubi *et al*. (2001); Manggoel *et al.* (2012); Uguru, (1995) have reported significant genetic differences as well as high heritability estimates for cowpea traits under various environmental conditions.

Significant genetic variability has been reported extensively in literature with respect to cowpea yield components under low P soil conditions. However, limited information is available on heritability. Ansah *et al*. (2014) screened cowpea accessions under two P treatments (low and high) and reported high heritability for total root length, lateral root numbers, root dry weight, nodule dry weight, shoot dry weight, total dry weight, shoot P content, P utilization efficiency. However, their conclusion was based on shoot and root biomass, no heritability estimates for the reproductive traits as well as yield and its components were determined in their work.

A breeding program for the development of high grain and/or fodder yielding cowpea varieties under low P soil environment was initiated as P deficiency is wide spread in upland agricultural soils where cowpea is most often grown in Niger (Nouri *et al.*, 2017). To this end we collected farmers' varieties from different cowpea growing areas of the country with the aim of quantifying the degree of their genetic diversity as well as estimating the heritability of yield related traits under low soil P conditions.

4.2. Materials and methods

The experiments were carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Sadore station, Niger. The research station lies on latitude 13°14'N and longitude 2°16'E and is located at an altitude of 235 m above sea level in Sahelian zone where the rainy season is between June and September. The mean annual rainfall between 1983 and 2015 is 556.92 mm with the peak being in August (ICRISAT unpublished). Sadore is situated 45 Km south of Niamey where the mean winter (December, January, and February) temperature is 25.3°C and mean spring (March, April and May) temperature is 32.7°C. The first trial was conducted in the rainy season while the second took place in the dry season.

4.2.1. Rainy season trial

The trial was carried out on plot C_8 which is low in total P and N according to the soil maps produced by the institute in 2011 (Figure 4.1 and 4.2).

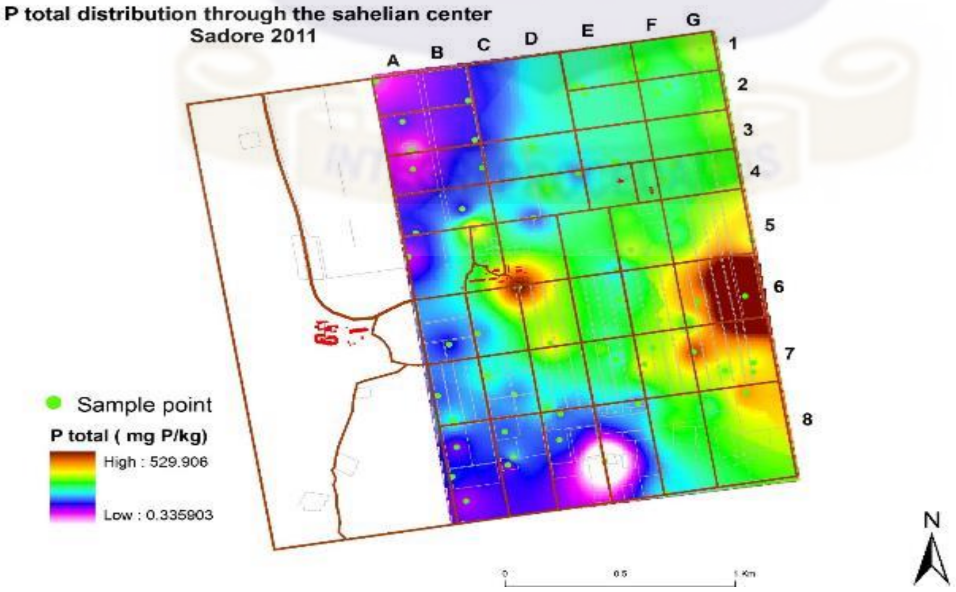


Figure 4-1 Distribution of total P in the ICRISAT sahelian center Sadore 2011

(Source: ICRISAT Sadore farm unit)

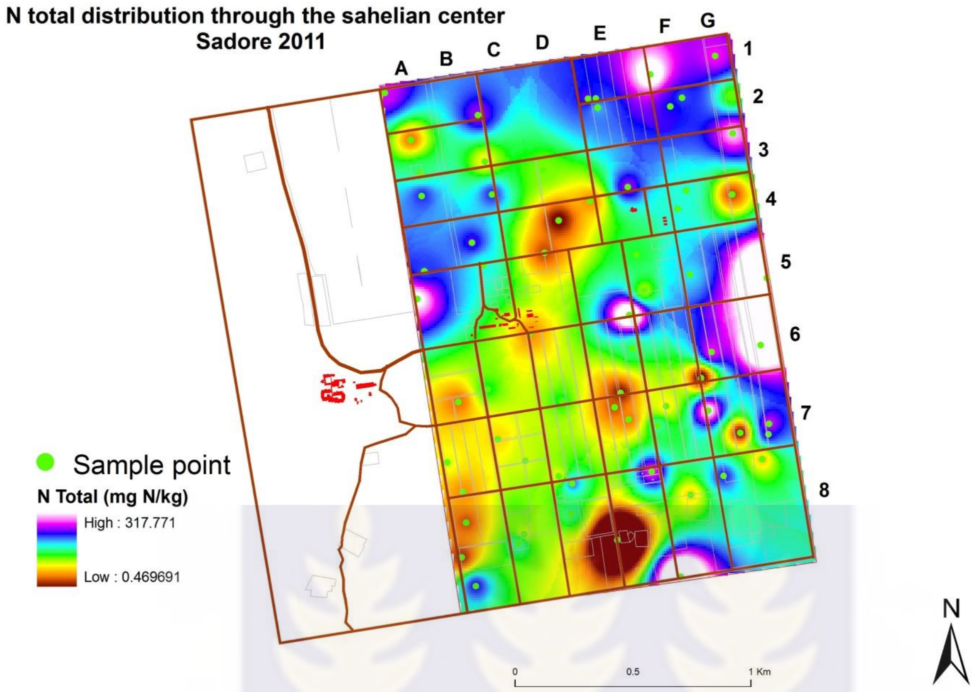


Figure 4-2. Total N distribution in the ICRISAT sahelian center Sadore 2011.

(Source: ICRISAT Sadore farm unit)

Plot C_8 has been on fallow since 2013. Soil samples were collected from the plot to determine the P level and as well as some nutrients composition. It was divided into 3 blocks and soil samples were collected at 0-20 and 20-40 cm depths from each. Results of the soil analysis showed that the site was low in available P (6.42 ppm) although the level has increased during the fallow period. The soil was also acidic and poor in nitrogen (N), potassium (K), sodium (Na), organic matter (OM), magnesium (Mg) and exchangeable acidity (EA); the calcium (Ca) content was however medium (Table 4.1)

Table 4.1. Some chemical properties of plot C_8 soil at ICRISAT Sadore

Soil properties	**0-20**	**20-40**	**Mean**
pH	5.60	5.17	5.39
Ca	6.10	5.63	5.87
Mg	0.13	0.07	0.10
Na	0.14	0.13	0.14
K	0.07	0.17	0.12
AE	0.14	0.32	0.23
Available P	6.18	6.65	6.42
C	0.23	0.16	0.20
OM	0.39	0.26	0.33
N	0.02	0.02	0.02

The weather data covering the period of the trial were recorded by the ICRISAT Sadore weather station. Data include information about rainfall, temperature, relative humidity, solar radiation, soil temperature and wind (Table 4.2). The rains lasted for 4 months (June, July, August and September). The total rainfall was 572.4 mm. The total monthly rainfall ranged from 85 mm in June to 202.5 mm in August. The relative humidity (min and max) was lower at the beginning and end of the season and higher in the middle of the season with the peak in August. Although there was not much variation in air temperature between months, June and October had the highest means with 36.4 and 38.1°C respectively. The two months also had the highest evaporation. Solar radiation data was obtained for August, September and October only and the maximum value was recorded in October. The wind speed was high in the beginning of the season, decreased in the middle and rose towards the end.

Table 4.2. Weather data of 2016 rainy season at ICRISAT Sadore, Niger

Month	Rain	AirT_Min	AirTC_Max	RH_Max	RH_Min	SOLAR	ST05-07	ST05-13	ST10-07	ST10-13	WIND	Evap.
June	85	26.1	36.4	73.3	47.7		29.4	44.5	30.5	37.7	4.6	6.98
July	186.6	24.4	33.4	87.9	63.3		27.2	39.5	28.1	34.4	3.3	4.5
Aug	202.5	23.5	32.3	92.5	67.8	19.8	26.1	37.3	27	32.8	2.8	4.2
Sept	98.3	23.4	33.8	90.5	59.5	19.6	26.9	41.8	28	36.2	2.1	4.2
Oct	0	23.4	38.1	75.7	34.4	21.3	27.2	50.1	30.8	38.6	2.4	6.3

Evap. = evaporation, Min TP = minimum temperature, Max TP = maximum temperature, HUM-07= min relative humidity, HUM-13 = maximum relative humidity, SOLAR = solar radiation, ST05-07 = min soil temperature at 5 cm depth, ST05-13 = max soil temperature at 5 cm depth, ST10-07 = min soil temperature at 5 cm depth, ST10-13 = max soil temperature at 10 cm depth.

Units: rain (mm); AirT_Min, AirT_Max, AirT_Min, ST05-07, ST05-13, ST10-07, ST10-13 (°C); RH_Min and RH_Max (%); Solar (W/m^2); Wind (meters/second); Evap (mmday-1).

The tested cowpea germplasm lines were made up of 150 accessions that were planted on June 30th, 2016. The germplasm included 22 improved varieties, six wild relatives and 122 local cultivars. The improved lines were composed of 16 from IITA, four from ICRISAT and two from INRAN. The local accessions consisted of five from ICRISAT, Sadore genebank, three from Burkina, one from United States of America (USA) and 114 from farmers. The latter were collected during a survey in the cowpea growing areas of Niger Republic in 2015. The farmers ‘varieties collection survey was conducted in 52 villages of the 3 major cowpea production regions of the country which are Maradi, Dosso and Zinder. Seeds samples were collected from 15 villages in Maradi, 19 in Zinder and 18 in Dosso. These villages were visited for the collection based on information obtained from extension services as well as farmers. The sites of the collection are indicated on the Niger Republic map (Figure 4.3).

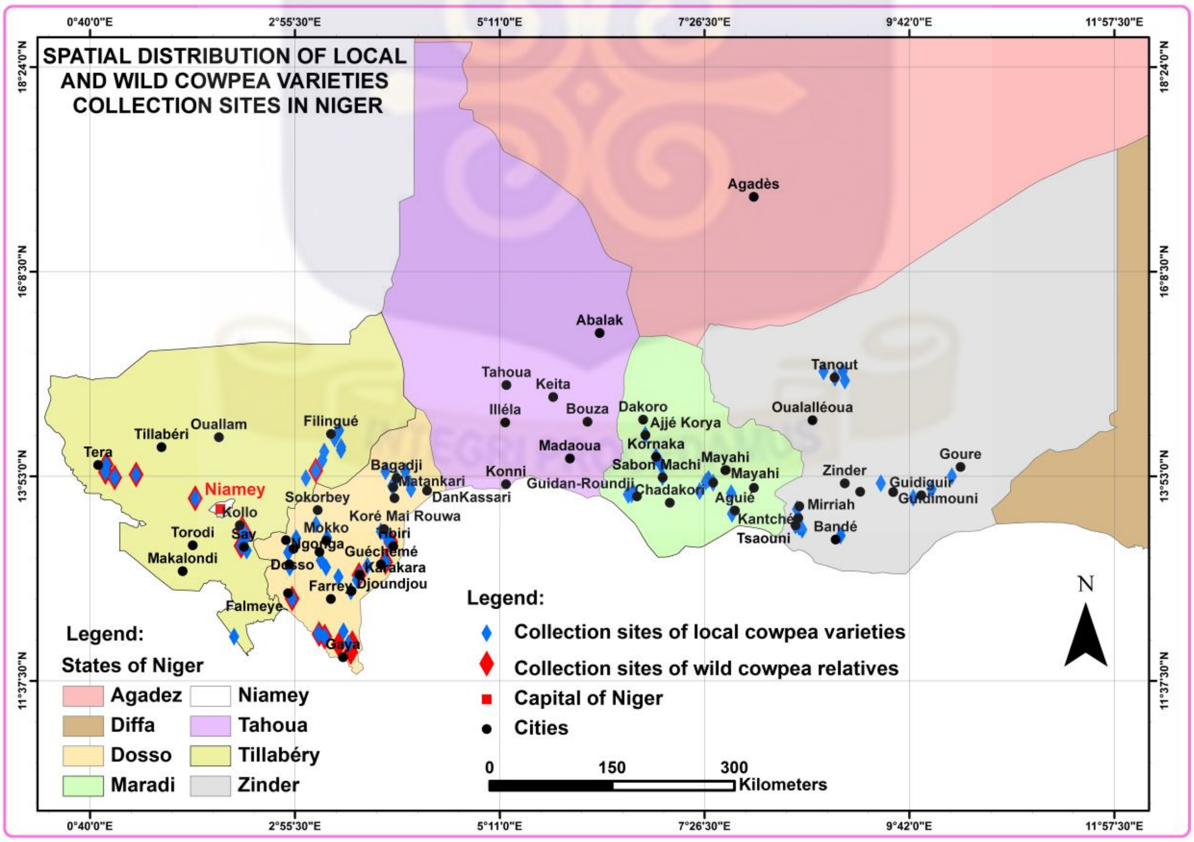


Figure 4-3. Distribution of sites where local cowpea varieties were collected

Before planting, the field was ploughed; small trees mostly *Guera senegalensis* were uprooted while big ones were slashed to avoid shading. The residues of both trees and grass were removed from the field to reduce soil organic matter content.

The genotypes were planted in a 10 x 15 alpha lattice design with three replications. The blocks were 14 m long and 6 m wide, and aligned from 1 to 15 in each replication. The distance between blocks was 2 m. The replications were also separated from one another by a distance of 2 m. The lines were planted each in two rows of 6 m length with a spacing of 0.5 m intra and 1 m inter rows. Each plot contained 24 hills. Borders were planted 1 m apart from the first row on each side of the field. Seeds were sterilized with Thioral (25 % Hyperchlor, 25 % Thirame) prior to planting. Four seeds were planted per hill and thinned to 2 plants at 21 days after planting (DAP).

After emergence, a guard was hired for three weeks to prevent birds and squirrels from uprooting the plants to feed on cotyledons. Only one weeding was done at three weeks after planting. Eight different types of insecticides were applied through14 treatments from 4 to 14 weeks DAP to control a variety of insects. The insects included grasshoppers, aphids, *Clavigralla spp*, and caterpillar pod borer. Insecticide application was halted on October, 6th 2016, when we realized that it was no more efficient. Despite all these insecticide treatments, two of the insects, namely *Clavigralla tomentosicollis* and pod borer were not controlled successfully.

Destructive sampling method was used to collect plant samples at eight weeks after planting (WAP) for determination of shoot dry weight (SDWt). Plants were randomly harvested from six hills in each plot i.e. two hills at the beginning, two in the middle and two at the end. Plant samples were dried under room temperature and weighed using an electronic scale. Plant height was recorded also at the time of plant sample collection for SDWt determination.

Clavigralla tomentosicollis attack started around eight WAP when early and medium maturing varieties started setting pods. An assessment of tolerance was carried out on 63 DAP using a one to four rating scale with 1= Resistant (No insect found on the plants and no pod was attacked or destroyed), 2 = Tolerant (the plant is invaded by insects, but the majority (above 70 %) of the pods were not destroyed), 3= Susceptible (the pods were destroyed, except few), 4 = very susceptible (All the pods were destroyed and dropped, the peduncle of the plants bore no pod at all). Data were also collected on days to flowering (DAF), days to 50% maturity (MAT50), and grain yield (Gyield) per plant.

The collected data were subjected to analysis of variance using Breeding View 1.5.0.16982 statistical software. The software runs two analyses automatically. In the first analysis, genotypes were treated as random effects to estimate genetic variance components and heritability (Equation (1)) (random terms underlined):

$$\underline{y_{ij}} = \mu + \underline{block_j} + \underline{Genotype_i} + \underline{error_{ij}}, \ (1)$$

The model includes a fixed intercept μ, and the random effects of $\underline{block_j} \sim N(0,\sigma^2\ b)$, $\underline{genotype_i} \sim N(0,\sigma^2\ g)$), and $\underline{error_{ij}} \sim N(0,\sigma^2)$.

The estimated variance components are used in the second analysis, where genotypes were moved to the fixed part of the model. This model with random genotypic effects was used to obtain Best Linear Unbiased Predictions (BLUP) of the genotypes.

In the second analysis, genotypes were treated as fixed effects, so the model was changed to Equation (2)

$$\underline{y_{ij}} = \mu + \underline{block_j} + Genotype_i + \underline{error_{ij}} \ (2)$$

In this model, the variance components other than the error were not estimated, but the ones obtained from model1 were used. They were used to obtain adjusted means or Best Linear Unbiased Estimates (BLUE), which will be used in GxE.

The phenotypic variance (VP), the phenotypic coefficient of variation (PCV), the genetic coefficient of variation (GCV) were estimated using the formulae below

$$V_P = \sigma^2_g + MSe$$

$$GCV = (\sqrt{\sigma^2_g}/X)\ 100$$

$$PCV = (\sqrt{\sigma^2_p}/X)\ 100$$

Where σ^2_g = genotypic variance; MSe = mean squares of error; X is the grand mean for the measured traits, and σ^2_p = phenotypic variance.

Principal component analyses (PCA) and correlation among traits were also carried out.

4.2.2. Dry season experiment

There were no irrigation facilities on the site that hosted the rainy season trial; the dry season test was hence conducted on the A_3 experimental plot. According to previous soil tests, A_3 was poor in P. The site had been on fallow for two years. Soil tests revealed that the field is acidic, low in available P, Carbon, Ca, K as well as Cation Exchange Capacity (CEC) (Table 4.3).

Table 4.3. Chemical soil characteristics of the minor season trial site

Soil properties	**0-20cm**	**20-40cm**	**Mean**
pH H_2O (1/2.5)	4.49	4.49	4.49
pH KCl (1/2.5)	4.25	4.27	4.26
Carbon	0.23	0.18	0.24
P total (ppm)	10.53	9.47	10.00
P assimilable (ppm)	5.62	4.78	5.20
Ca (meq/100)	2.63	2.50	2.57
K (meq/100)	0.10	0.10	0.10
CEC (meq/100)	5.00	6.00	5.50

The trial was conducted under irrigation. The germplasm was composed of two hundred (200) genotypes which consist of 135 already tested in the previous trial and 65 other accessions. The latter were made up of two lines from University of Maradi, one wild cowpea relative; eight most widely adapted improved varieties and 54 local lines collected from farmers in October 2016 from the regions of Tillaberi and Dosso in Niger.

Planting took place on February 4th, 2017 after the field was ploughed and harrowed. The experimental design was a 10 X 20 alpha lattice design with 3 replications. Seed treatment, sowing and thinning were carried out as in the above trial. Seedlings that failed to emerge were supplied 2 weeks after sowing. Each block measured 3 m long and 14 m wide. Every line was planted on two rows of 3 m with the same spacing as the rainy season experiment. The blocks were separated by 1.5 m while the replications were 4 m apart. Border rows were planted 1 m from replications. The plants were watered twice a week. The field was sprayed twice with insecticide to control aphids.

The data collection and analysis were carried out the same as the first trial. However, in addition to the previous experiment, fodder yield (Fyield), harvest index (HI) and hundred seed weight (HSWt) were recorded.

4.3. Results

4.3.1. Genetic variation

In the rainy season, highly significant differences were detected for days to flowering (DAF), days to 50 % maturity (MAT50), plant height (PHt) and grain yield (Gyield) at $p < 0.001$ while pod sucking bug (PSB) was significant at at $p = 0.001$. There were no significant differences in shoot dry weight (SDWt). The largest variance was observed for plant height while the smallest was in pod sucking bugs (PSB) damage score (Table 4.4).

Table 4.4 Mean square and variance of genotypes and blocks for traits in the rainy season

	Mean square		
Traits	Genotypes	Block	Variance
DAF	146.45***	2.38	174.00
MAT50	49.64***	0.21	48.00
PHt	925.5***	761.6**	2604.00
SDWt	14.2	79.3**	225.90
Gyield	78.9***	37.5*	285.60
PSB	0.06***	0.21***	0.43

*significance at 0.05, **significant at 0.01 ***significance at ≤ 0.001 probability level, DAF =days to flowering, MAT50 = days to 50 % maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, PSB = pod sucking bugs.

The mean, range and median for the traits are given for Table 4.5 below.

Table 4.5 Summary statistics for traits in the rainy season

Traits	Mean	Range	Median
DAF	57.00	64.00	52.00
MAT50	83.00	28.00	81.00
PH	150.8	279.00	152.00
SDWt	30.90	101.80	27.50
Gyield	29.77	103.70	28.01
PSB	3.42	2.00	4.00

DAF =days to flowering, MAT50 = days to 50 % maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, PSB = pod sucking bugs.

The mean number of days to flowering was 57 varying from 36 to 100. The genotypes that flowered early were G5, G22 and G49 with a mean of 40.48, 41.23 and 41.99 days after planting, respectively. G139, G60, G55 which flowered respectively 96.89, 93.98 and 92.94 days after planting were the last genotypes to set flowers. Days to 50 % maturity ranged from 77 to 105 days after planting with an average of 83. G100, G3, G2 were among the earliest maturing varieties while G39, G50 and G41 were part of those that matured late. Plant height ranged from 10 to 289 cm with a mean of 150.8. The median plant height of 152 cm revealed that the germplasm evaluated in the present study were mostly made up of prostrate to semi-prostrate genotypes. The results showed also that there was substantial genetic diversity among the lines under investigation with regards to shoot dry weight per plant. The minimum shoot dry weight was 7.91g while the maximum was 109.7 g. The accessions with highest dry plant weight were G134 (63.51 g), G85 (58.48 g) and G99 (54.57 g). Similarly wide variation among tested lines was detected with respect to grain yield which ranged from 0.73 to 104.38 g per plant. The mean grain yield was 29.77 g and the superior genotypes were G118, G62, G150 and G116 with 67.62, 60.02, 56.64 and 55.46 g per plant respectively. The plants were attacked by pod sucking bugs (PSBs) throughout the podding stage . In an effort to control the insects, several treatments using a variety of insecticides were carried out; the applied chemicals were however able to slow down the insects development only for a few weeks. The insects population build up was very high towards the end of the season despites the treatments resulting in a complet yield loss of late maturing varieties. The scoring results showed that all the genotypes were susceptible to PSBs, except Dan Missira and Yawa 04 which expressed some moderate level of tolerance .

In the results of the dry season experiment, high significant differences at p <0.001 were detected for all the traits except the shoot dry weight. The blocks were also significantly different for days to 50 % maturity, plant height, shoot dry weight and grain yield (Table 4.6).

Table 4.6 Mean square and variance of genotypes and blocks for traits in the dry season

	Mean square		
Traits	Genotypes	Block	Variance
DAF	10.56^{***}	1.34	25.63
MAT50	6.34^{***}	1.18^{**}	16.11
PHt	61.90^{***}	56.9^{***}	406.3
Shoot dry weight	0.21	11.59^{***}	43.13
Gyield	42.70^{***}	51.1^{***}	224.2
Fyield	1101.20^{***}	212.7	1866.00
HI	0.05^{***}	0.008	0.0909
HSWt	4.93^{***}	0.00	7.67

*significance at 0.05, **significant at 0.01 ***significance at ≤ 0.001 probability level, DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, Fyield = fodder yield, HI = harvest index, HSWt = hundred seed weight.

Traits with large total variance values were fodder yield, plant height and grain yield in descending order. In terms of coefficient of variation, fodder (62.63 %) and grain (54.5%) yield were also the traits where high estimates were observed. Other traits with high CV values were shoot dry weight and harvest index with 51.70 and 60.23 % respectively. Hundred seed weight got the lowest estimates of both CV and variance. The total variance revealed that largest variability among genotypes resides in the fodder and to some extent in grain yield.

The median showed that at least half of the lines under investigation started flowering at 53 DAP. The number of days to flowering ranged from 42 to 65 days after planting and the mean was 52.59 (Table 4.7). The varieties that flowered early were G205, G49 and G20 while G201, G84 and G208 flowered late.

Table 4.7 Summary statistics for traits in the dry season

Trait	Mean	Range	Median
SDWt	12.70	51.83	11.86
DAF	52.59	23.00	53.00
MAT50	72.99	30.00	72.00
PHt	45.10	144.20	40.67
Gyield	27.46	122.30	25.82
Fyield	68.98	279.10	60.00
HI	0.50	1.65	0.48
HSWt	16.68	26.78	16.58

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, Fyield = fodder yield, HI = harvest index, HSWt = hundred seed weight

Even though no significant differences were detected among accessions regarding SDWt, large variation was observed as it ranged from 1.38 to 53.20 g. Genotypes with higher shoot dry weight per plant were G211, G190 and G70 which were all local varieties. Taking into account the median of 72 days after planting for days to 50 % maturity, the results revealed that majority of the lines belong to the medium class of maturity. MAT50 ranged from 55 to 85 DAP, thus showing the presence of some early and late maturing varieties in the tested germplasm. Plant height ranged from 10.80 to 155.00 cm, however the mean was 45.10. The minimum grain yield per plant was 0.314 while the maximum was 122.30 g. The mean grain yield per plant was 27.46 g and the most promising accessions were G118, G108 and G150. Large variability was also detected in the case of fodder yield; it had the largest range of 279.10 and varied from 10.91 to 290.00 g per plant. Genotypes with high fodder yield include G164, G197, G118 and G27. Harvest index (HI), a parameter that helps to classify varieties as source of grain, fodder or dual purpose showed considerable variation in this study. It ranged from 0.003 to 1.65. Varieties with high HI were classified as grain source; those with intermediate were dual purpose while the ones having low HI were forage source. According to our results, G205, G146 and G20 can be used for grain production while G164, G197 and G202 could serve as excellent source of fodder. In terms of dual purpose cultivars, G118 had an HI of 0.61 and was among superior lines with respect to both grain and fodder, thus it was a well indicated candidate for such uses. The results regarding hundred seed weight showed that the germplasm under investigation was composed of small, medium and large seed size lines since it varied from 3.67 to 30.45 g. However, most of them were of medium size seeds as shown by a mean value of 16.68 g as well as a median value of 16.58 g.

Comparison of the results obtained from the two studies revealed that lower means were recorded in the dry season as compared to the rainy season for all the traits (Table 4.8).

Table 4.8 Summary statistics for traits in rainy and dry seasons

Traits	MEAN		MEDIAN		RANGE		VARIANCE		CV(%)	
	RS	DS	RS	DS	RS	DS	RS	DS	RS	DS
DAF	57.00	52.59	52.00	53.00	64.00	23.00	174.00	25.63	23.00	9.635
MAT50	83.00	72.99	81.00	72.00	28.00	30.00	48.00	16.11	8.00	5.50
PHt	150.8	45.10	152.00	40.67	279.00	144.20	2604.00	406.3	33.84	44.69
SDWt	30.90	12.70	27.50	11.86	101.80	51.83	225.90	43.13	48.64	51.70
Gyield	29.77	27.46	28.01	25.82	103.70	122.30	285.60	224.2	56.76	54.5

RS = rainy season, DS = dry season

The difference between the two seasons was larger with regards to mean plant height (150.8 cm in rainy season and 45.10 cm in dry season) and shoot dry weight (30.90 and 12.70 g for rainy and dry seasons, respectively). Three types of genotypes were detected regarding the mean days to flowering stability in the two seasons:

- Genotypes whose number of days to flowering remained approximatively the same in both seasons. Almost all the early maturing varieties belonged to this group
- Genotypes that flowered early in the rainy season and relatively late in the minor season; an example was G5 which had the mean DAF of 40.48 in the rainy season and 57.96 days in the dry season.
- Genotypes that flowered late (≥ 69 DAP) in the rainy season but relatively early in the dry season (< 57 DAP); this group is composed of late maturing varieties. Examples are given in Table 4.9 below. The observed difference ranged from 18.03 for G34 to 43.42 days for G141.

Table 4.9 Days to flowering of photosensitive varieties in both seasons

CODE	DESIGNATION	DS	RS	DIF
G34	Bougou Bougou	57.95	75.97	18.03
G74	Baadare Karanguiya	53.04	71.58	18.54
G41	Kwaama Maiki	49.92	69.40	19.49
G78	Lakade Maiki	53.53	80.14	26.60
G120	Lakade karanguiya	49.71	77.31	27.59
G27	Hannoun Mareni Shalla	49.73	78.39	28.66
G94	Sabon Kafi sababba sata	56.26	87.88	31.61
G83	Tanout marche	54.27	91.46	37.19
G141	Kolalla Dan arbain	48.39	91.81	43.42

DS = minor season; RS = rainy season; DIF = difference between the 2 mean days to flowering

In terms of MAT50, the difference between means of rainy season and dry season was narrow because in the rainy season, all the late maturing varieties were not able to reach 50 % maturity as a result of PSB attack.

Some genotypes consistently produced high grain yield in both environments (Table 4.10). G131 and G11 performed even better in the minor season. These superior and stable cultivars can therefore be used as varieties and/or sources of genes in breeding programs.

Table 4.10 Superior genotypes with regards to grain yield in both seasons

CODE	DESIGNATION	DRY SEASON	RAINY SEASON
G118	Botsotsuwa	57.22	67.62
G150	Jiraini Oubanzaoura	53.50	56.64
G149	Waken chaibou	42.31	52.97
G131	Dan Saley	45.67	34.08
G11	Local chical	43.66	34.68

4.3.2. Variance components and heritability

The estimates of genetic variance, phenotypic variance, genetic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) and heritability for the rainy season are shown in Table 4.11. The residual term variance was greater than the genetic variance in plant height, shoot dry weight, grain yield and pod sucking bugs. In contrast genetic variance was higher than that of the error in days to flowering and days to 50 % maturity. The highest values of genetic variance were recorded in plant height and days to flowering. The GCV and PCV ranged from 1.30 to 24.77 and 2.50 to 35.40 respectively. Heritability estimates varied from 92.51 % in DAF to 21.05 % in SDWt. MAT50, PHt, and Gyield recorded 85.02, 70.56 and 53.05 % respectively as heritability values.

Table 4.11 Estimates of variance components and broad-sense heritability in the main season

Traits	σ^2e	σ^2g	σ^2p	GCV	PCV	h^2
DAF	25.75	146.45	172.2	16.03	17.38	92.51
MAT50	8.333	49.64	57.97	7.73	8.36	85.02
PHt	964.7	925.5	1890.2	24.77	35.4	70.56
SDWt	131.9	14.2	146.1	6.78	8.9	21.05
Gyield	165.4	78.9	244.3	16.28	28.65	53.05
PSB	0.156	0.06	0.21	1.30	2.50	31.59

DAF =days to flowering, MAT50 = days to 50 % maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, PSB = pod sucking bugs.

In the dry season, the partition of variance into its different components showed that the residual term variance was considerably greater than the genetic variance for DAF, MAT50, PHt, Gyield and SDWt traits. This resulted in a significantly high phenotype variance observed in these traits (Table 4.12). In contrast, the genetic variance was substantially higher than that of the error term in the case of fodder yield and in hundred seed weight. Harvest index, fodder yield, hundred seed weight, days to 50 % maturity and days to flowering recorded broad-sense heritability estimates of 80.72, 80.6, 71.94, 70.88 and 70.75 % respectively. GCV and PCV were also calculated and the results are given in Table 4.12. GCV values ranged from 1.29 for dry shoot weight to 39.96 % in fodder yield while the estimates of PCV varied from 4.13 % for harvest index to 49.76 % for fodder yield. Grain yield recorded 12.46 as GCV and 23.78 as PCV.

Table 4.12 Estimates of variance components and broad-sense heritability in the dry season

Traits	$\sigma 2e$	$\sigma^2 g$	$\sigma^2 p$	GCV	PCV	h^2
DAF	12.15	10.56	22.71	4.48	6.57	70.75
MAT50	6.715	6.34	13.05	2.95	4.23	70.88
PHt	229.6	61.90	291.50	11.72	25.42	38.18
SDWt	24.26	0.21	24.47	1.29	13.88	1.88
Gyield	112.6	42.70	155.30	12.46	23.78	48.53
Fyield	607.00	1101.20	1708.20	39.96	49.76	80.6
HI	0.0324	0.05	0.09	3.26	4.13	80.72
HSWt	3.05	4.93	7.98	5.44	6.92	71.94

DAF =days to flowering, MAT50 = days to 50 % maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, PSB = pod sucking bugs, Fyield = fodder yield, HI = harvest index, HSWt = hundred seed weight.

Taking into account, the results of the two seasons, higher estimates of heritability, genetic variance, phenotypic variance as well as GCV and PCV were obtained in the rainy season.

4.3.3. Correlation between traits

The results of correlation analysis for the rainy season experiment revealed the existence of both positive and negative relationships among traits (Table 4.13). Grain yield was positively correlated with shoot dry weight, plant height and shoot color ; it was however negatively correlated with days to flowering and days to 50 % maturity. Shoot dry weight had the highest positive correlation with grain yield. It was however surprising to notice that SDWt was inversely related to plant height. The most high positive correlation was found between days to flowering and days to 50% maturity traits confirming that early flowering leads to early maturity. Similarly a positive correlation was observed between MAT50 and PSB indicating that early maturing varieties were likely to escape PSB attack compared to late maturing because they may reach maturity before the build up of the insect population.

Table 4.13 Genetic correlation coefficient among traits in the rainy season

Biomass	1	-						
COLOR	2	–0.01	-					
DAF	3	0.04	–0.14	-				
Height	4	–0.02	–0.04	–0.016	-			
MAT50	5	–0.07	–0.17	0.60	0.00	-		
PSB	6	0.02	0.04	–0.04	0.01	0.01	-	
Yield	7	0.23	0.13	–0.26	0.17	–0.35	0.10	-
		1	2	3	4	5	6	7

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, PSB = pod sucking bugs.

The dry season trial correlation results showed that grain yield was positively correlated with all the traits except hundred seed weight. Its positive relationship was only strong with SDWt (0.57) and moderate with harvest index (0.35) (Table 4.14). The most important positive correlation was observed between DAF and MAT50 (0.72). Fodder yield was positively associated with SDWt, plant height and MAT50, the relationship was however higher with SDWt, MAT50 and plant height in ascending order. On the other hand strong negative correlation was detected between fodder yield and harvest index.

Table 4.14 Genetic correlation between traits in the dry season

SDWt	1	-							
DAF	2	–0.12	-						
Fyield	3	0.14	0.18	-					
HSDWt	4	0.06	–0.33	–0.10					
HI	5	0.24	–0.46	–0.69	0.22				
MAT50	6	–0.10	0.72	0.30	–0.23	–0.40	-		
PHt	7	0.48	0.04	0.40	0.03	–0.32	–0.12	-	
Gyield	8	0.57	0.10	0.10	–0.11	0.354	0.11	0.16	-
		1	2	3	4	5	6	7	8

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, Fyield = fodder yield, HI = harvest index, HSWt = hundred seed weight.

4.3.4. Principal component Analysis (PCA)

In the rainy season trial, the two first components of the PCA biplot explained 92.35 % of the observed variation with PC-1 accounting for 82.74 % and PC-2 for 9.61 %. The first component was highly associated with plant height while the second was related to grain yield and shoot dry weight (Table 4.15).

Table 4.15 Principal components analysis for the rainy season trial

Traits	1	2	3	4	5
SDWt	0.12	0.37	0.92	-0.01	0.05
DAF	-0.04	-0.16	0.05	0.77	0.61
Height	0.99	-0.12	-0.08	0.02	0.02
MAT50	0.00	-0.15	0.11	0.59	-0.79
Gyield	0.08	0.89	-0.36	0.25	-0.04
PCA	82.74	9.61	5.10	2.19	0.36
Eigenvalues	2695.6	313.1	166.0	71.4	11.7

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, PCA = principal component axis

In the dry season trial, 86.71 % of the variation was explained by the two first axis of PCA with 69.77 % for PC-1 and 16.94 % for PC-2. PC-1 had a strong positive correlation with fodder yield whereas the PC-2 was highly associated with plant height and grain yield (Table 4.16).

Table 4.16 Principal components analysis for the dry season trial

Traits	1	2	3	4	5
SDWT	0.06	0.24	-0.08	0.01	0.86
DAF	0.00	-0.07	0.00	0.78	-0.16
Fyield	0.96	-0.29	0.03	-0.05	0.00
HI	0.00	0.01	-0.01	-0.01	0.00
HSWt	-0.01	0.02	0.02	-0.17	0.28
MAT50	0.03	-0.07	0.02	0.60	0.32
PHt	0.23	0.80	0.53	0.07	-0.16
Gyield	0.17	0.46	-0.85	0.06	-0.16
PCA	69.77	16.94	9.35	2.03	0.87
Eigenvalues	1140.2	276.8	152.8	33.3	14.3

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, Fyield = fodder yield, HI = harvest index, HSWt = hundred seed weight, PCA = principal component axis.

4.4. Discussion

According to Hazelton and Murphy (2007), P content in soil less than 12 ppm are low. With a mean P level of 6.42 and 5.20 in the rainy and dry seasons respectively, the sites used in current study were accordingly very low in P; thus qualifying it for hosting the trials to determine genetic variability and heritability of cowpea traits under low P soil conditions.

Despite the different environmental conditions, high significant difference was detected in both seasons with regards to days to flowering, days to 50 % maturity, plant height and grain yield. The present findings corroborated with Omoigui *et al.* (2005), Ansah *et al*. (2014) and Gerrano *et al*. (2015) who reported significant variability in all measured traits. However the present study results, disagreed with theirs with respect to shoot dry weight no significant differences were observed among genotypes in both seasons concerning that trait. SDWt data were recorded at 8 WAP for all the genotypes, Rothe *et al.* (2014) collected SDWt data at flowering time of each cultivar and detected highly significant difference among lines; this is an indication that their method may be more appropriate for investigating genotype divesrsity with regards to that trait.

Mean days to flowering of 52.59 in the dry season and 57 days in the rainy season were significantly higher than the range of 36 to 42 for days to 50 % flowering reported by Ishiyaku and Singh (2003) in Nigeria. Lower means were also reported by Gerrano *et al*. (2015) in South Africa, Nagalakshmi *et al.* (2010) in India, Cabbinah *et al.* (2011) in Ghana and Ehlers and Hall (1997) in USA. The higher values observed in the current study could be attributed to the presence of large number of local varieties in the screened germplasm which were known to be generally highly photosensitive and/or late maturing. It can also be due to the effect of the environmental factors since Hadley *et al.* (1983) stated that temperature and photoperiodism have an influence on time to flowering. With an overall mean of 78 days after planting for days to 50 % maturity, findings of the present study revealed that most of the genotypes tested belonged to the medium class of maturity according to Dugje *et al.* (2009) maturity classification. The mean plant height of 150.8 cm obtained in the rainy season was in agreement with Nwosu *et al.* (2013) who reported a range of 134.29 cm at Ibadan and 159.73 cm at Keffi in Nigeria. However significantly lower plant height (41.5 cm) was recorded in the dry season and this could be a sign of genotype by environment interaction. Similar plant height values were revealed by the study of Animasaun *et al.* (2015) who stated that plant height ranged from 40.5 to 68.59 cm among 10 cowpea cultivars. Large variation was observed between the means of the two seasons with regards to shoot dry weight per plant as considerably higher values were obtained in the rainy season when environmental conditions seemed to be more favorable for legume crops production. Despite the low available P of the sites, some genotypes were able to produce very high grain yield per plant, expressing therefore high level of tolerance. The best cultivar recorded a mean yield of 67.62 g in the rainy season and 57.22 g in the dry season. Slightly lower values were reported by Nwosu *et al.* (2013) while evaluating the genetic variability, heritability and genetic advance in cowpea cultivars. However our results were not in agreement with Ojo *et al*. (2007) who got 29.73 g as mean grain yield per plant for the P tolerant parent when studying the genetics of P utilization in tropical cowpea. Similarly Gerrano *et al*. (2015) stated that the best genotype in their study yielded 29.9 g grain per plant. From the results, we observed that genotypes with high fodder yielding potential during the dry season existed within the germplasm under evaluation. A very narrow variation was observed regarding the mean grain yield per plant between the two seasons. Taking into account the non-significant difference between grain yield mean per plant in the two seasons, we can conclude that the minor season also provides a condusive environment for cowpea production provided irrigation facilities are available. Despites the weather conditions that made prostrate and semi-prostrate to become semi-erect and semi-erect to become erect, some genotypes were not affected and produced high amount of fodder. These genotypes which included G164, G197 and G27 can be used for forage production under irrigation or via the flood recession cropping to solve the problem of feed shortage that occurs most often during the dry season.

The partition of variance into its different components showed that the variabilty due to the genetic constitution of genotypes varied among seasons as well as traits. Despite the fact that more accessions were involved in the minor season experiment, lower genetic variance was observed in that season compared to the main season for all the traits, thus the expression of the genetic diversity of genotypes may be restricted by the weather conditions prevailing in the dry season. For example despites the addition of 50 lines in the dry season to the 150 evaluated during the major season, the genetic variance detected in the rainy season with respect to days to flowering and plant height was respectively 14 and 15 times greater than that observed in the dry season. The greater residual term variance in comparison to genetic variance observed in plant height, shoot dry weight and grain yield in both seasons indicated that environmental factors contribution to the variability detected in the present work with regard to these traits was sizeable. These results corroborated with Ajayi *et al.* (2014) and Inuwa *et al*. (2012). However, Uguru (1995) obtained a slightly greater genetic to residual variance for grain yield while investigating the association between heritability and variability of yield and yield components in vegetable cowpea. Similarly higher genetic variance than error variance was reported by Manggoel *et al*. (2012) with respect to days to 50 % flowering and grain yield. Their findings contrasted with those of the current study regarding grain yield but agreed with it concerning days to flowering and hundred seed weight. Genetic constitution of the tested genotypes has played a major role in the variability revealed by the present study with regard to fodder yield, hundred seed weight and harvest index since the genetic variance was greater than that of the error term.

GCV and PCV estimates were considered as high, medium or low when their values are respectively > 20, between 10 and 20 and < 10 according to Deshmukh *et al.* (1986). Accordingly, our results showed that only plant height in the rainy season and fodder yield in the dry season recorded large GCV while the traits with high PCV include days to flowering, plant height and grain yield. Both large GVC and PCV were reported by Manggoel *et al.* (2012), Gerrano *et al.* (2015) with regard to grain yield, however in the present work only large PCV was detected for that very trait. Sufficient variation with respect to plant height, days to flowering, fodder and grain yield warranting selection existed in the tested genotypes taking into account their GCV and PCV values obtained in the present work.

Heritability estimates for a trait determine the extent to which it can be transmitted from parents to offspring. According to Burton and Devane (1953) the progress that can be achieved through selection is determined jointly by heritability and GCV estimates. Pramoda and Gangaprasad *(*2007) classified heritability estimates ≥ 80 % as very high, 60 to 79 % as moderately high, 40 to 59 % as medium and < 40 as low. According to their classification, the findings of the present study indicated that very large heritability values were obtained for days to flowering, fodder yield and harvest index; moderately high estimates were recorded for hundred seed weight, days to 50 % maturity while moderate values were observed for grain yield. Similar results were reported by Idahosa *et al*. (2010), Omoigui *et al*. (2006), Gerrano *et al. (*2015) and Manggoel *et al*. (2012). The present findings were however not in agreement with Gerrano *et al*. (2015) regarding grain yield who reported moderately high heritability. In contrast, Inuwa *et al.* (2012) reported very low heritability with respect to days to 50 % flowering and days to 90 % maturity. From the current results, fodder yield combined both large GCV as well as very high heritability; it could therefore be improved easily and efficiently through selection. Selection of superior genotypes with regard to grain yield is also possible since the trait recorded medium GCV and heritability values.

4.5. Conclusion

The results of the present study revealed that high diversity with regard to yield and yield related traits exists in the evaluated germplasm, hence selection could be carried successfully. High to medium heritability was also detected for yield and its components. However both the diversity and heritability were higher in the rainy season compared to the dry season. In the rainy season, grain yield was positively correlated with shoot dry weight and plant height; it was however negatively correlated with days to flowering and days to 50 % maturity. The dry season trial correlation results showed that grain yield was positively correlated with all the traits except hundred seed weight.

Cowpea cultivars with high grain, fodder and/or both were identified and can be used as varieties or as parents in improvement programs.

CHAPTER FIVE

5.0. Assessment of genotype by environment interactions for yield and its components under low P conditions

5.1. Introduction

The increasing cowpea production observed in recent years in Niger was mainly due to expansion of cultivation area rather than yield improvement. Now, new cropping land is scarce as population growth rate is high (Pender *et al.*, 2008). Consequently, the mean cropping area per household has been reducing resulting in the reduction of the fallow period. Resource poor farmers are left with no choice than using marginal lands and/or continuous cultivation of the fields which soils are predominantly sandy and deficient in organic matter, nitrogen (N) and phosphorus (P), leading to a steady depletion of the meager soil nutrients. About 15 kg/ha of N, 2 kg/ha of P and 11 kg/ha of potassium (K) were mined from agricultural soils every year in Niger (Buerkert and Hiernaux, 1998). However, fertilizer application country wide is very low; on average basis, less than 1 kg/ha of mineral fertilizers was applied by farmers in Niger (Pender *et al.*, 2008). As a nitrogen fixing legume, cowpea can overcome N deficiency in soils; however Traore (1974) stated that crops respond minimally to N when P requirements are not met. In some soils, P may exist but not in the form that it is available to crops. However some genotypes have the ability of making sparingly soluble P available in its rooting zone through mechanisms such as root induced processes, root characteristics, mycorrhizal dependency, P uptake kinetics parameters, and rhizosphere processes (Nielsen and Barber, 1978; Nielsen and Shjorring, 1983; Nye and Tinker, 1977). Cowpea cultivars with high P use efficiency or tolerant to low P soil conditions have been reported extensively in literature. However most of these reports were based on studies conducted under screen house conditions. As a result, the yield stability of P efficient or tolerant genotypes remains largely under investigated. The success of a breeding program is most often dependent on genotype by environment interaction.

Multilocational evalutation allows an unbiased estimation of the yield and also helps in predicting the performance of a cultivar under predictable and unpredictable weather conditions, thereby allowing the identification and selection of stable and high yielding genotypes (Kamdi, 2001). Yield is a trait highly influenced by environment, thus varieties with high yield over a large number and various environments are scarce. Adewale *et al.* (2010) asserted that breeders recommendation of varieties to different locations is influenced by G x E interactions, therefore when the interaction is large, specific recommendations are made to environments.

Stability of yield and its components in cowpea were assessed under twelve environments in Egypt (El-Shaieny *et al.*, 2015). They detected significant G x E for all the characters except in pod length, hundred seed weight and pod weight per plant. Nevertheless, they were able to identify some stable genotypes such as Dokii 331 and Cream 12. G x E interaction with regard to flowering date, pod maturity and grain yield in cowpea was also reported by Aliyu and Makinde *(*2016) when phenotyping 21 cowpea breeding lines for seed yield and yield components in the southern Guinea Savanna of Nigeria. However, a significant environmental effect on soybean genotypes with respect to seed yield per plant in the humid southeast parts of Nigeria was detected by Nwofia *et al.* (2016). But they noticed some level of G x E in TGx 1448-2E and TGx 1485-1D genotypes with respect to number of pods per plant.

Amara and Suale (1996) evaluated cowpea cultivars in multi-environments for P use efficiency in Sierra Leone and observed large G x E interaction in terms of yield. They identified two lines (IT86D-1010 and IT86D-716) with high performance, however these varieties were not stable over all the test environments as they produced poor yield in low rainfall areas. Also some genotypes with high P use efficiency were selected for use in improvement programs by Abaidoo *et al.*, 2017 following a two years evaluation in the Northern Guinea savanna of Nigeria.

Soils in Niger, across the agro-ecological zones, are low and variable in P content, in such situation, organic and mineral fertilizer application may help in obtaining high yield, but development of cultivars with high P use efficiency or tolerant to deficient P soils may undoubtedly provide a better alternative to resource poor farmers. In the present study, local cowpea varieties were evaluated for tolerance to low P soil conditions in four environments with the aims of:

- assessing of G x E interactions for yield and its components
- evaluating and selecting stable and high yielding cultivars for recommendations to growers
- identifying superior genotypes for use in varietal improvement programs

5.2. Materials and methods

5.2.1. Experimental sites

The trials were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Sadore and Institut National de la Recherche Agronomique du Niger (INRAN), Maradi, Niger.

Sadore lies on latitude 13°14'N and longitude 2°16'E at an altitude of 235 m above sea level in Sahelian zone where the rainy season is between June and September. The mean annual rainfall between 1983 and 2015 is 556.92 mm with the peak being in August (ICRISAT unpublished). Sadore is located 45 km south of Niamey where the mean winter (December, January, and February) temperature is 25.3°C and mean spring (March, April and May) temperature is 32.7°C.

The ICRISAT's experimental fields used were C_8 and A_3. These sites were low in P and N according to the 2011 soil map of the statition (see Fig. 4.1 and 4.2 in Chapter four). Also the analysis of soil samples collected at 0 – 20 and 20 – 40 cm from the two sites confirmed the low P content of their soils (Table 4.1 and 4.4 in Chapter four).

Data on rainfall, temperature, relative humidity and solar radiation were obtained from Sadore ICRISAT's weather station. The environmental factors varied only slightly between 2016 and 2017 rainy seasons (Figure 5.1).

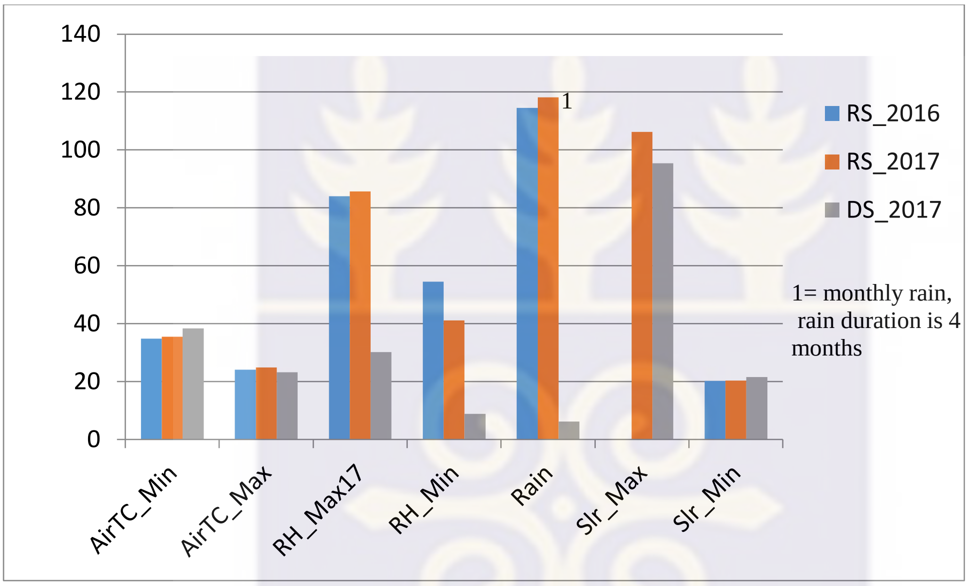


Figure 5-1 Weather data of ICRISAT Sadore for 2016 and 2017 rainy seasons

However, relative humidity, solar radiation and rainfall differed significantly between the rainy (June, July, August and September) and dry (February, March, April and May) seasons (Figure 5. 2). Rainfall and relative humidity were also variable within the rainy season; they were low at the beginning of the season, reached the peak towards the middle and started dropping from the end of August.

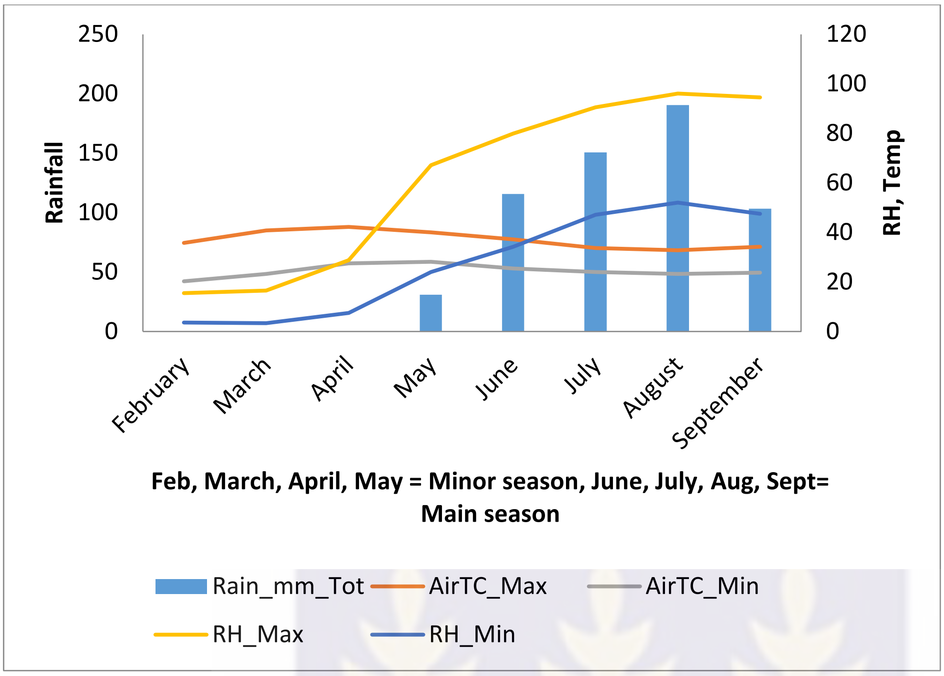


Figure 5-2 Variation of weather factors between rainy and dry season

Maradi is located in the southern part of Niger republic at latitude 15°26’ N, longitude 8°33’ E and altitude of 383 m above sea level. Its Soil is 90 % sand, 8 % clay, and 2 % silt with a pH of 6.5. No confirmed information was available about soil P content of the study site. However it is P deficient according to the station management. Mean rainfall from 2010 to 2016 was 517.18 mm. Minimal and maximal mean temperatures were 21.6 and 35.8 from 2010 to 2014.

5.2.2. Germplasm

The study was conducted in four different trials during 2016 and 2017. The number of genotypes tested varied from one trial to another. The first trial (E1) took place in the rainy season of 2016 when 150 lines were evaluated. The second trial (E2) was carried using 200 genotypes in the dry season of 2017. The third (E3) and fourth (E4) trials were conducted during the 2017 rainy season at Sadore and Maradi respectively. In the last two trials, 28 genotypes made up of promising genotypes selected from the results of the two first experiments together with some widely adopted improved varieties by farmers (Table 5. 1). Fiften promising genotypes that cut across the 4 trials were used in the assessment of genotype by environment interaction.

Table 5.1 Cowpea varieties used for the trials at Sadore and Maradi during 2017 rainy season

No	ENTRY_CODE	VARIETY NAME	TYPE	ORIGIN
1	206	KVX30-309	Improved	INERA (Burkina Faso)
2	209	TN5-78	Improved	(INRAN) Niger
3	187	NELOC-187	Local	Niger
4	165	NELOC-165	Local	Niger
5	33	Dan batsatsa	Local	Niger
6	1	Gorom Local	Local	Burkina Faso
7	131	Dan Saley Kornaka	Local	Niger
8	43	Farin wake Kantari	Local	Niger
9	149	Waken chaibou	Local	Niger
10	62	Dan Baouchi Dan Saga	Local	Niger
11	173	NELOC-173	Local	Niger
12	108	Tamalalo Araouraye	Local	Niger
13	48	Dan Gawouna Gourgouzou	Local	Niger
14	176	NELOC-176	Local	Niger
15	146	Jan Pass Ismihou	Local	Niger
16	96	Dan Raha	Local	Niger
17	11	Local chical	Local	Niger
18	32	Matarka Nawa Issufuri	Local	Niger
19	118	Botsotsuwa Ishirnawa	Local	Niger
20	150	Jiraini Ouban zaoura Jaja	Local	Niger
21	116	Yagaou Dan saga	Local	Niger
22	98	NDIAMBOUR	Local	Niger
23	197	NELOC-197	Local	Niger
24	115	Bahaouche Mai Tsakoni	Local	Niger
25	205	IT90K-372-1-2	Improved	IITA
26	101	Karadua Garam Tsofua	Local	Niger
27	164	NELOC-164	Local	Niger
28	125	Bonbohi Fabirdji	Local	Niger

5.2.3. Method

The first experiment (E1) was planted on 30th June in a 10 x 15 alpha lattice design with three replications. The blocks were 14 m long and 6 m wide. The distance between blocks was 2 m. The replications were also separated from one another by a distance of 2 m. The lines were planted each in two rows of 6 m length with a spacing of 0.5 m intra and 1 m inter rows. Each plot contained 24 hills.

The second experiment (E2) was carried out under irrigation. The planting took place on February 4th, 2017. The experimental design was a 10 X 20 alpha lattice design with 3 replications. Supply of missing hill was carried out two weeks later. Each block measured 3 m long and 14 m wide. Each line was planted on two rows of 3 m with the same spacing as the first experiment. The blocks were separated by 1.5 m while the replications were 4 m apart.

The third (E3) and fourth (E4) trials were planted on 4th July Sadore and 20th June at Maradi in the 2017 rainy season. The design was a 4 X 7 alpha lattice with 3 replications. The plot area was 16 m^2. The spacing consisted of 0.8 and 0.5 m inter row and intra plants respectively.

For all the trials, seeds were sterilized with Thioral (25 % Hyperchlor, 25 % Thirame) prior to planting. Four seeds were planted per hill. At 21 days after planting (DAP), the plants were thinned to 2 per hill for E1 and E2 and 1 per hill for E3 and E4. Border lines were planted 1m apart from the first row on each side of the experiment. Weeds and insects were controlled as necessary.

5.2.4. Data collection

Data were collected on both agronomic, yield and yield related traits which included the following:

- shoot dry weight (SDWt) : Plants were uprooted from four hills in each plot at 8 weeks after planting, dried at room temperature and weighted ;
- plant height (PHt) : The tallest two plants selected randomly per plot were measured using a tape measure at 8 weeks after planting;
- days to flowering (DAF): number of days from planting to flowering;
- days to 50 % maturity (Mat50): number of days from planting to 50 % maturity;
- grain yield per plant (Gyield): dry seed weight per plot divided by the number of plants per plot;
- fodder yield per plant (Fyield) : dry fodder weight per plot divided by the number of plants per plot;
- pod yield (Pyield) : dry pod weight per plot divided by the number of plants per plot;
- harvest index (HI):Grain yield/biological yield x 100;
- hundred seed weight (HSWt),
- pod length (Plength), the length of two to three normal dry pods per plot was measured with a ruler;
- number of seeds per pod (NSPd): the number of seeds contained in two to three normal dry pods per plot was determined;
- Threshing percentage (Thresh): the weight of dry grains per plot over the weight of dry pods per plot x 100;
- The field at Maradi was highly infested by striga. The genotypes were scored for tolerance/susceptibility using a rating scale adapted from Singh and Emechebe (1997).

The striga density (DS) which is expressed as the number of emerged striga shoots per plot over the surface area of the plot was calculated.

The data on fodder yield and hundred seed weight were collected at three environments (E2, E3 and E4) while that on pod yield, pod length, seed number per pod and threshing percentage were measured at two environments (E3 and E4).

5.2.5. Data analysis

Data were subjected to the combined analysis of variance using SAS 9.4. AMMI which has on one hand, an additive component accounting for genotype and environment main effects and on the other, a multiplicative terms that models G x E was performed to study the patterns of G x E and to determine differential adaptation of genotypes to environments. The model is as follow:

$$\mathrm{Y}ij = \mu + Gi + Ej + \sum_{\mathrm{k=1}}^{\mathrm{k}} {}^{\lambda}\boldsymbol{k}\mathrm{Y} + \underline{\epsilon}_{ij}$$

GGE (G plus GxE) biplots which is similar to AMMI except that the multiplicative terms include the genotypic main effect in addition to GE was run to:

- directly identify the best performing genotypes,

- determine the mega environments (group of environment with same best performing genotypes).

AMMI analysis was not performed for traits that were measured at only two environments. Combined anova and AMMI analysis of variance tables for each trait were attached to the appendix.

Percentage contribution of IPCA1, IPCA2 and the residual to G x E variation was calculated by dividing the sums of square of each of them by that of the interaction times 100. It was however calculated only when both IPCAs were significant.

AMMI sum of squares was partitioned into its different components in order to determine the contribution of genotypes, environment, G x E and the error to the total variation observed in each trait. The contribution of each factor was determined by dividing its sum of squares by the total sum of squares and then multiplies the result by 100.

AMMI stability values were calculated using the formula below:

$$ASV(i^{th} Genotype) = (((SSPCA1/SSPCA2) * PCA1score_i)^2 + (PCA2score_i)^2)^{1/2}$$

ASV: AMMI stability value

SSPCA1: sum of squares of PCA1

SSPCA1: sum of squares of PCA2

PCA1score: PCA1 score for the ith genotype

PCA1score: PCA1 score for the ith genotype

PCA2score: PCA2 score for the ith genotype

GGE biplot analysis was carried out to determine the mega-environments as well as the winning genotypes per mega-environment using Genstat 12 statistical software. The winning genotype for a mega-environment is the vertex cultivar at the intersection of the two polygon sides whose perpendicular lines form the boundary of that environment.

Test environment with longer vectors are the ones that discriminate the genotypes better; if the environment has a short vector, it means the performance of all the genotypes is similar within that environment; the difference between cultivars cannot therefore be detected.

The representativeness of the environments is determined according to the angle formed by the environment and the average environment coordination (AEC), tests environments that have small angle with AEC are more representative than the ones having large angle.

The results from the data collected on striga infestation were not shown since the attack occurred only at one site.

5.3. Results

Combined anova as well AMMI analysis results showed significant differences ($p < 0.01$, $p < 0.001$) among genotypes for days to flowering, plant height, days to 50 % maturity, pod length, pod, grain and fodder yield and harvest index. No significant differences were however detected for shoot dry weight and seed number per pod. Environments were also significantly different ($p < 0.01$, $p < 0.001$, $p = 0.05$) for all the traits except for pod length and seed number per pod. Moreover, significant ($p < 0.01$, $p < 0.001$) genotype by environment interactions (G x E) were detected for days to flowering, days to 50 % maturity, pod yield per plant, fodder yield per plant, harvest index and threshing percentage (Tables 5.2 and 5.3).

However AMMI PCA components (IPCA1 and IPCA2) were significant only for days to flowering, days to 50 % maturity and fodder yield. Cumulative percentage of PCA axis accounted for 93.66 % and 84.51% of the total GEI variation in days to flowering and days to 50 % maturity respectively. But, in the case of fodder yield, the whole GEI variation was due to the PCA components with the residual having zero contribution.

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Table 5.2 Level of significance of factors for the traits under study (combined analysis)

SOV	DAF	MAT50	PHt	SDWt	Gyield	Snber	Plength	Pyield	Fyield	HI	Thresh%
Rep(Env)	34.99**	29.41	7358.22***	749.59***	824.82**	3.32	3.44	1641.60***	973.34	0.039	86.20
Block(Rep)	3.02	17.21	2854.71**	291.78	367.33	3.53	2.12	122	1261.63*	0.013	48.92
Env	690.45***	1650.48***	113156.36***	35446.00***	5959.83***	2.76	0.3	607.84*	6006.90***	0.036	48.46
Genotype	113.18***	56.81***	1832.53**	131.36	722.86***	2.86	7.65**	756.53***	6641.93***	0.086***	134.72
Env*Genotype	70.17***	48.86***	984.13	163.00	291.94	4.58	3.06	472.73**	1932.27***	0.054**	174.37*
Error	10.21	15.04	742.03	142.14	44.68	2.28	2.58	161.93	577.66	0.024	83.37

*significance at 0.05, **significant at 0.01 ***significance at $\leq$ 0.001 probability level, DAF =days to flowering, MAT50 = days to 50 % maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, Fyield = fodder yield, HI = harvest index,Snber = number of seeds per pod, Plength = pod length, Pyield = pod yield, Thresh% = threshing percentage

Table 5.3 Mean squares of factors for traits (AMMI analysis)

SOV	DAF	MAT50	PHt	SDWt	Gyield	Fyield
Treatments	117.00^{***}	158.70^{***}	7492.00^{***}	2035.00^{***}	801.00^{***}	3902.00^{***}
Genotypes	127.30^{***}	65.00^{***}	2096.00^{**}	151.00	861.00^{***}	7689.00^{***}
Environments	691.00^{***}	2121.40^{***}	124134.00^{***}	37097.00^{***}	7500.00^{***}	6007.00^{**}
Block	34.10^{**}	26.50	5763.00^{***}	616.00^{***}	847.00^{**}	851.00
Interactions	72.50^{***}	49.80^{***}	959.00	158.00	302.00	1869.00^{***}
IPCA	143.00^{***}	86.70^{***}	1232.00	264.00^{*}	399.00	2393.00^{***}
IPCA	40.30^{***}	27.20^{*}	1130.00	124.00	242.00	1269.00^{*}
Residuals	16.10	27.00	395.00	58.00	243.00	
Error	9.80	15.20	859.00	151.00	255.00	646.00
Total	46.20	62.60	3246.00	787.00	447.00	1725.00

*significance at 0.05. **significant at 0.01 ***significance at ≤ 0.001 probability level, DAF =days to flowering, MAT50 = days to 50 % maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yieldFyield = fodder yield.

The partitioning of the AMMI sums of squares into its different components revealed the contribution of every treatment factor as well as the error term to the variation observed in each measured traits (Table 5.4). The contribution of genotype to the variation varied from one trait to the other. The largest contribution of the genotypes was observed for fodder yield (46.76 %) while the smallest was for shoot dry weight (1.5 %). The genotypes were also responsible for a significant variation with regards to days to flowering (21.57%) as well as grain yield (15.06 %). The environment was the main cause of the variability detected in shoot dry weight, plant height, days to 50 % maturity and grain yield with 82.45 %, 72.04 %, 58.69 % and 36.55 % respectively. The GEI part of the variation was high for days to flowering (36.85 %), fodder yield (22.73 %) and days to 50 % maturity (18.66 %). The GE interaction, although not significant for grain yield, contributed considerably (15.85 %) to the yield variation. The error has a great contribution in the variation observed in grain yield (32.54%).

Table 5.4 Partitioning of total AMMI sum of square into its different components

SOV	DAF	SDWt	PHt	MAT50	Fyield	Gyield
Genotype	21.57	1.50	5.05	8.12	46.76	15.06
Environment	28.39	82.45	72.04	58.69	6.94	36.55
GE	36.85	4.72	6.93	18.66	22.73	15.85
Error	13.19	11.33	15.98	14.54	23.57	32.54
Total	100.00	100.00	100.00	100.00	100.00	100.00

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yieldFyield = fodder yield.

5.3.1. Days to flowering (DAF)

A relatively narrow variation was recorded among environmental means regarding days to flowering. Early flowering occurred at E3 compared to E2 and E4. E1 was comparatively intermediate in terms of days to flowering. The highest heterogeneity of variance was obtained at E4 (Figure 5.3).

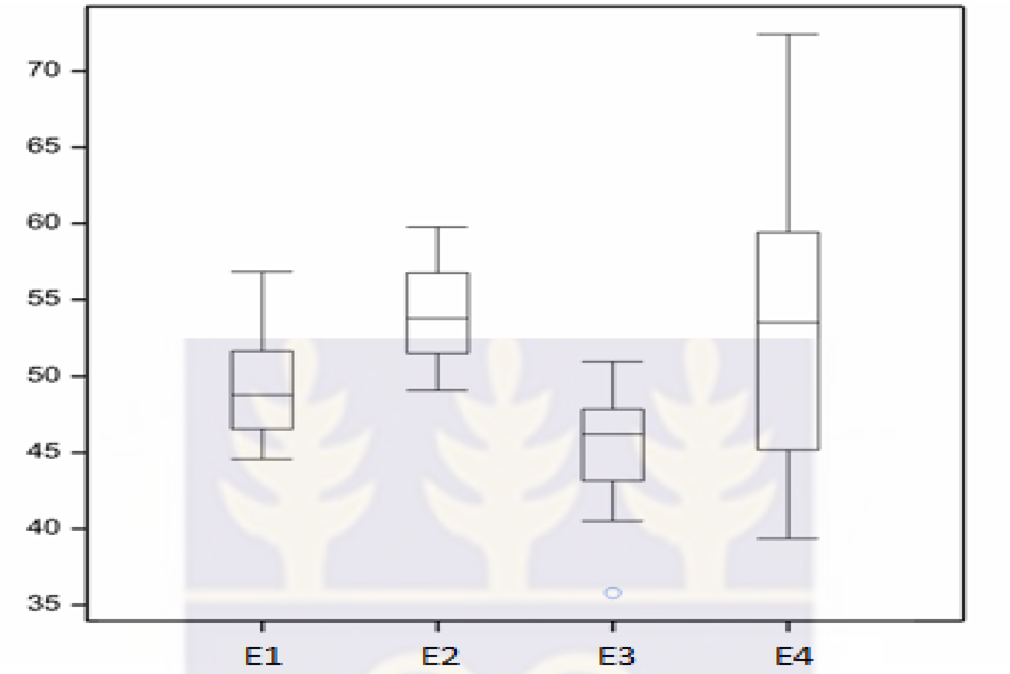

Figure 5-3 Boxplots for means of days to flowering across environment

The overall mean number of days to flowering ranged from 44.54 days after planting in G98 to 56.75 in G32. G108 was the most stable genotype with an AMMI stability value (ASV) of 1.61 (Table 5.5).

Table 5.5 Mean days to flowering of genotypes over all the environments

Code	**Genotype**	**E1**	**E2**	**E3**	**E4**	Mean	**ASV**
G108	Tamalalo	48.00	59.67	46.67	54.67	52.25	1.61
G149	Waken chaibou	52.00	56.00	48.00	58.00	53.50	1.84
G116	Gnagaou	57.00	51.67	49.33	53.67	52.92	1.9
G1	Gorom ocal	48.67	54.33	43.33	49.67	49.00	1.93
G125	Bonbohi	56.00	50.67	49.67	53.67	52.50	2.05
G146	Jan pass	45.67	49.33	40.67	44.33	45.00	2.62
G62	Dan baouchi	51.33	58.00	46.00	51.67	51.75	2.77
G150	Jiraini	50.67	53.67	46.67	59.33	52.58	3.93
G101	Karadua	51.00	55.67	45.33	47.33	49.83	4.45
G118	Botsotsuwa	46.00	52.67	48.00	44.00	47.67	4.69
G43	Farin wake	45.00	53.67	45.00	61.00	51.17	6.13
G96	Dan raha	47.67	57.00	43.67	44.00	48.08	6.45
G11	Local chical	48.67	51.33	41.33	62.67	51.00	7.66
G98	Ndiambour	45.50	57.33	36.00	39.33	44.54	8.89
G32	Matarka nawa	52.00	51.00	51.67	72.33	56.75	12.72
	Mean	**49.68**	**54.13**	**45.42**	**53.04**	**50.57**	

E1 = Sadore rainy season 2016, E2 = Sadore dry season 2017, E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017, ASV = AMMI stability value.

The results showed that the mean days to flowering at E3 was lowest compared to other environments.

Environments were grouped into 2 mega environments with regard to days to flowering. GGE biplot analysis found E1, E3 and E4 as similar environments and grouped them into one mega-environment. Genotypes with higher number of days to flowering were considered as superior cultivars by the software, so E1, E3 and E4 were put in the same mega environment because they shared the same winning line which was G32. E2 formed a different mega environment. The best performing cultivars in E2 was G108 (Figure 5.4).

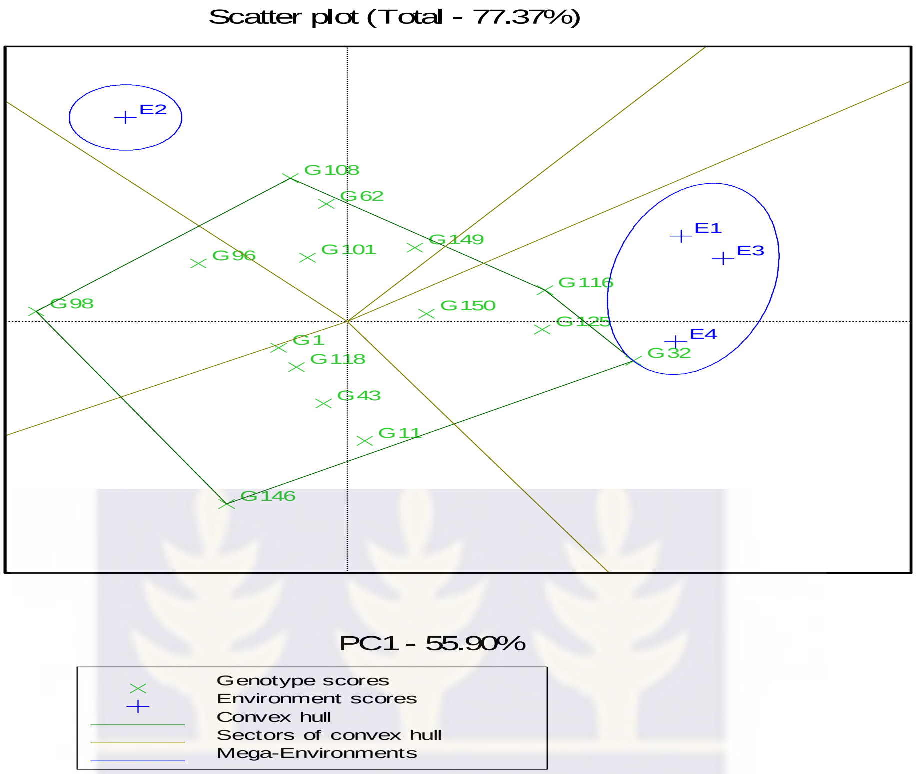

Figure 5-4 GGE biplots for days to flowering means

5.3.2. Shoot dry weight (SDWt)

The variation between environments was very large with regard to this trait as it can be seen in the boxplot for means of shoot dry weight (Figure 5.5). E4 had the highest mean and variance; it was therefore the most discriminating as well as most favorable environment for shoot development. The experiments of E2 and E3 were carried out on the same field and same year but different season with E2 being the minor season and E3 the main season of 2017. However the shoot dry weight per plant at E3 is more than double of that of E2 suggesting a significant effect of the season on the trait. On the other hand, E3 and E4 are the same year but different location and planting date, the results showed that the mean of E4 was more than double of that of E3.

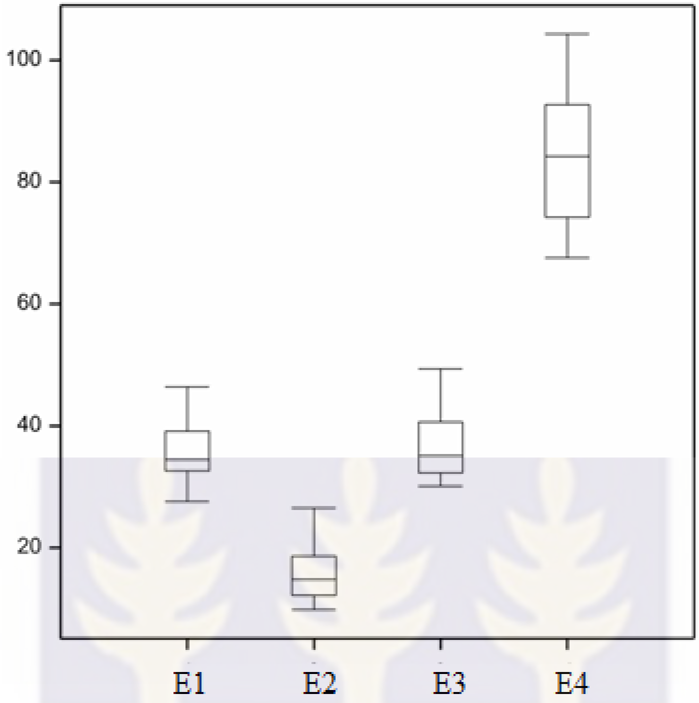

Figure 5-5 Boxplot for shoot dry weight means

The overall mean shoot dry weight ranged from 37.72 to 48.84 g per plant with G118 having the highest value and G96 recorded the lowest across locations (Table 5.6.). All the genotypes performed significantly better at E4 in comparison to the other environments. Despite being the line with the lowest shoot dry weight, G96 was the most stable as it recorded the smallest AMMI stability value (1.08).

Table 5.6 Mean shoot dry weight of genotypes across the environments

Code	Genotype	E1	E2	E3	E4	Mean	ASV
G96	Dan raha	27.56	9.11	33.55	80.67	37.72	1.08
G108	Tamalalo	40.04	13.86	35.62	88.33	44.46	1.81
G43	Farin wake	34.41	11.49	31.48	84.58	40.49	1.81
G32	Matarka Nawa	36.14	12.56	32.03	75.83	39.14	1.82
G125	Bonbohi	35.81	17.42	37.37	89.92	45.13	1.95
G101	Karadua	32.54	16.84	50.09	85.00	46.12	2.65
G98	Ndiambour	30.70	13.26	35.30	72.67	37.98	2.68
G149	Waken chaibou	32.63	20.26	32.75	73.17	39.70	2.83
G62	Dan baouchi	45.76	10.84	32.18	78.00	41.69	2.90
G118	Botsotsuwa	32.01	26.71	42.05	94.58	48.84	3.38
G11	Local chical	46.39	14.10	30.90	93.67	46.26	4.21
G146	Jan pass	33.33	19.24	29.53	97.50	44.90	5.97
G116	Gnagaou	38.81	11.51	38.63	101.83	47.70	6.12
G1	Gorom local	33.40	14.01	44.93	67.25	39.90	6.66
G150	Jiraini	42.01	17.32	42.35	66.50	42.05	7.40
	Mean	**36.10**	**15.24**	**36.58**	**83.30**	**42.81**	

E1 = Sadore rainy season 2016. E2 = Sadore dry season 2017. E3 = Sadore rainy season 2017. E4 = Maradi rainy season 2017, ASV = AMMI stability value.

Three mega environments were formed, E2 and E3 were grouped into the same mega-environment as they shared the same winning genotypes namely G1. E1 and E4 formed a mega-environment each. The best performing genotype at E1 was G62 while G116 won at E4 (Figure 5.6).

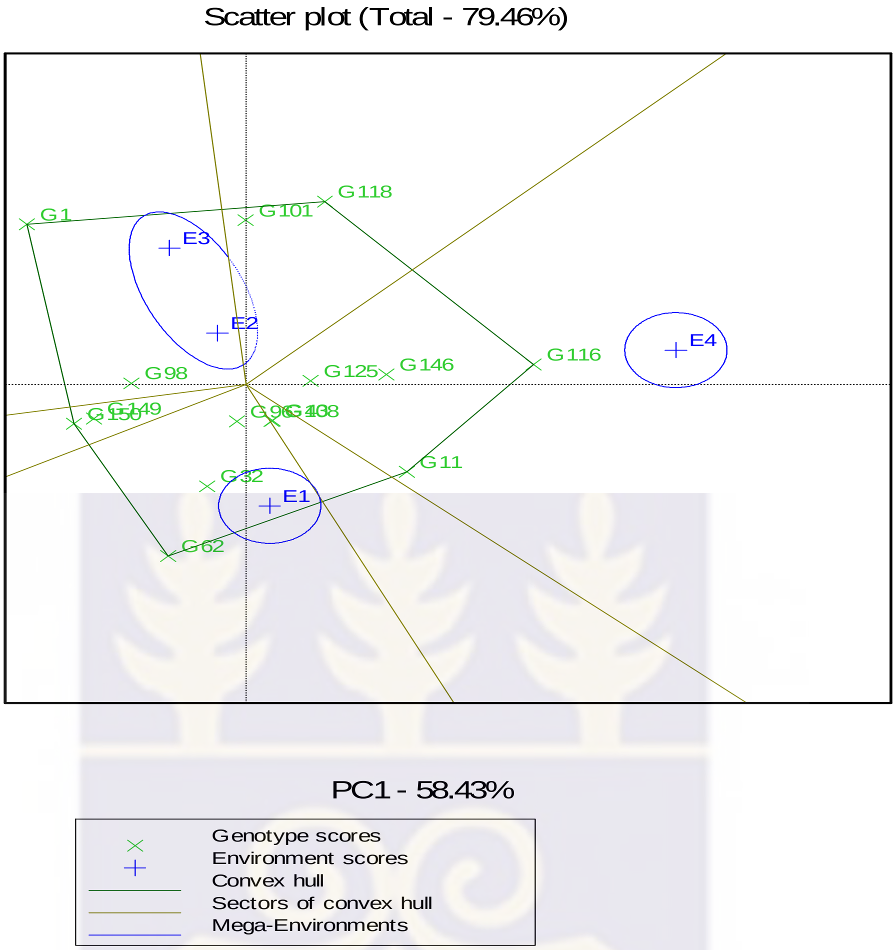

Figure 5-6. GGE biplots for shoot dry weight

5.3.3. Plant Height (PHt)

The variation of the mean plant height per environment is shown in the figure below.

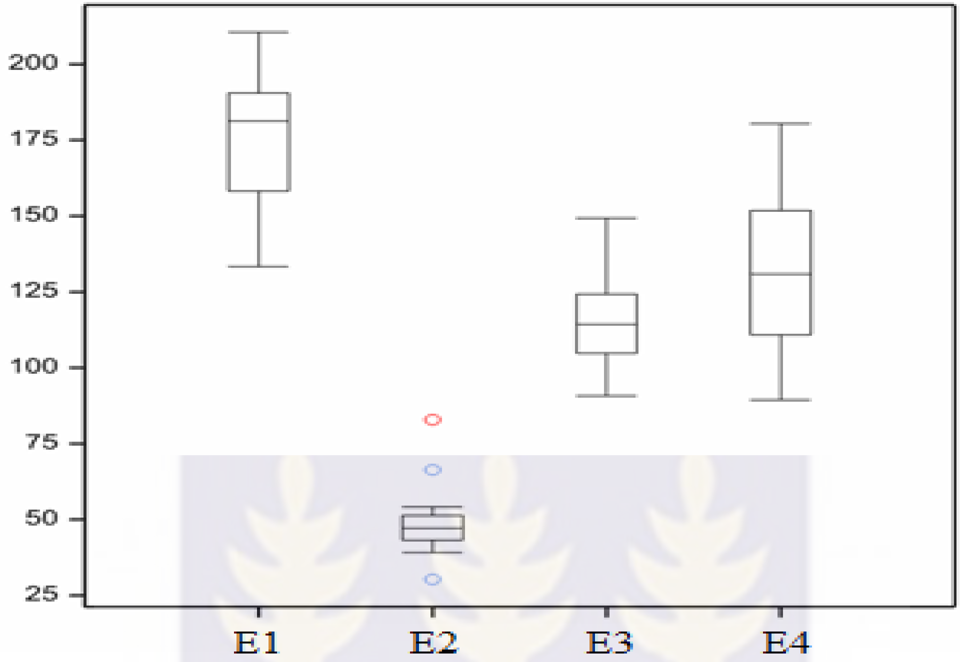

Figure 5-7 Boxplot for plant height means

The highest mean plant height was obtained at E1 while the largest variance was observed at E4. E2 had the lowest performance as well as the narrowest variation.

Large variation was detected among the tested genotypes regarding mean plant height (Table 5.7). It ranged from 100.68 to 145. 34 cm. G101 and G149 had the highest and lowest mean plant height respectively. The most and least stable genotypes were G125 and G150.

Table 5.7 Means plant height of genotypes across the environments

Code	Genotype	E1	E2	E3	E4	Mean	ASV
G125	Bonbohi	187.89	44.91	122.67	129.00	121.12	1.46
G1	Gorom local	164.00	44.35	122.33	112.83	110.88	1.89
G108	Tamalalo	186.22	48.11	118.67	119.83	118.21	2.11
G62	Dan baouchi	180.11	47.21	105.33	113.50	111.54	2.20
G118	Botsotsuwa	192.17	65.29	109.67	162.17	132.32	2.98
G11	Local	159.33	51.88	124.33	144.00	119.89	3.03
G101	Karadua	182.56	82.47	152.17	164.17	145.34	3.16
G149	Waken chaibou	135.67	53.56	102.00	111.50	100.68	3.60
G98	Ndiambour	163.50	43.09	111.50	89.33	101.86	3.63
G146	Jan pass	203.89	50.34	97.67	142.67	123.64	3.85
G116	Gnagaou	141.22	44.60	129.17	130.83	111.45	4.35
G96	Dan raha	208.44	38.75	140.50	182.33	142.51	4.52
G43	Farin wake	156.56	28.90	90.50	153.67	107.40	4.83
G32	Matarka nawa	205.67	49.19	111.00	111.67	119.38	4.98
G150	Jiraini	203.44	46.55	116.50	105.67	118.04	5.20
	Mean	**178.04**	**49.28**	**116.93**	**131.54**	**118.95**	

E1 = Sadore rainy season 2016. E2 = Sadore dry season 2017. E3 = Sadore rainy season 2017. E4 = Maradi rainy season 2017, ASV = AMMI stability value.

Only 1 mega environment was formed by the GGE as there was no re-ranking of genotypes according to environments. The superior genotypes were G96 and G101 (Figure 5.8).

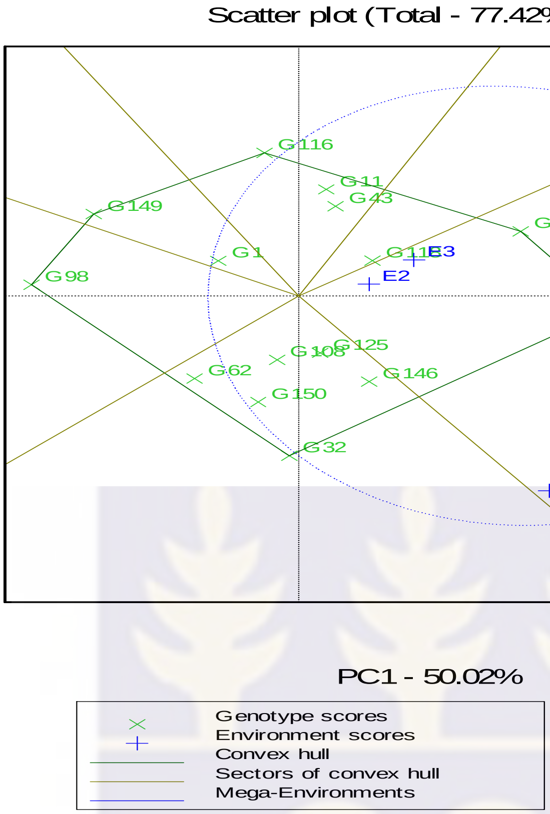

Figure 5-8 GGE biplots for plant height means

5.3.4. Days to 50 % maturity (MAT50)

The variation of the mean number of days to 50 % maturity according to environments is shown in the figure 5.9. It illustrated the heterogeneity of variance of the trait among environments. The largest variability was observed at E4. The highest mean was recorded at E4 while E3 got the lowest making it the best environment for early maturity.

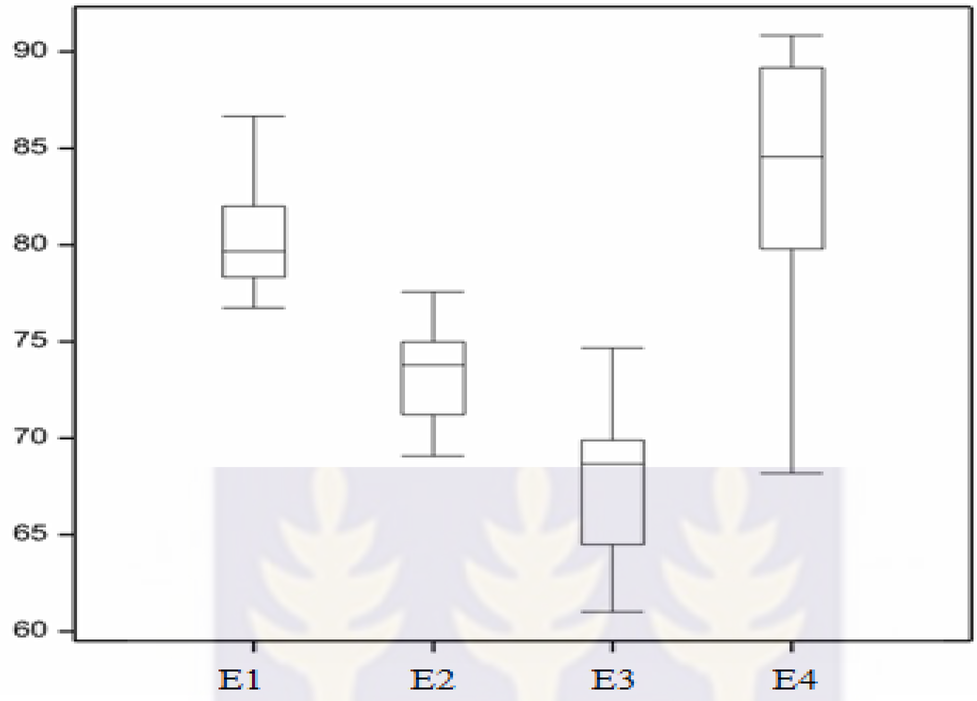

Figure 5-9 Boxplot for days to 50 % maturity means

The most stable genotype across the environments was G146 with an overall mean of 73.04 days after planting and an ASV of 0.96 (Table 5.8). General mean indicated that G96 was the first genotype to reach 50 % maturity. G98 exhibited a wide variability among environments; for example a difference of 24 days was observed between its means of E1 and E3. It is the most instable genotype with an ASV of 12.06 according to the results.

Table 5.8 Mean days to 50 % maturity for genotypes across the environments

Genotype	Designation	E1	E2	E3	E4	Mean	ASV
146	Jan pass	79.18	69.66	62.90	80.42	73.04	0.96
1	Gorom local	76.51	72.21	67.44	81.58	74.43	1.13
118	Botsotua	76.68	75.33	68.79	80.73	75.38	1.19
11	Local chical	81.75	70.83	62.76	84.39	74.93	1.23
43	Farin wake	79.48	71.68	69.85	79.50	75.13	1.28
116	Gnagaou	85.77	72.88	70.23	86.45	78.83	1.38
125	Bonbohi	83.39	70.55	71.23	85.51	77.67	1.75
150	Jiraini	80.13	75.38	68.12	90.28	78.48	3.30
62	Dan baouchi	77.00	76.19	67.37	89.75	77.58	3.77
149	Waken chaibou	78.05	75.84	68.67	88.28	77.71	3.86
108	Tamalalo	78.19	77.58	68.44	90.04	78.56	3.99
101	Karadua	80.72	72.76	68.70	76.53	74.68	4.16
96	Dan raha	76.72	74.92	64.00	73.10	72.18	5.18
32	Matarka nawa	78.10	69.68	75.42	90.61	78.45	6.36
98	Ndiambour	86.09	73.46	61.13	68.52	72.30	12.06
Mean		**79.85**	**73.26**	**67.67**	**83.05**	**75.96**	

E1 = Sadore rainy season 2016, E2 = Sadore dry season 2017, E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017, ASV = AMMI Stability Value.

The GGE biplots grouped the environments into 3 mega environments (Figure 5.10). It considered genotypes with highest number of days to maturity as the best ones. E3 and E4 belonged to the same mega-environment with G32 as the winning genotype. The early maturing variety at E3 and E4 was G98. E1 and E2 formed each a mega environment. The winning cultivars at E1 were G116 and G125 while G62 and G96 won at E2.

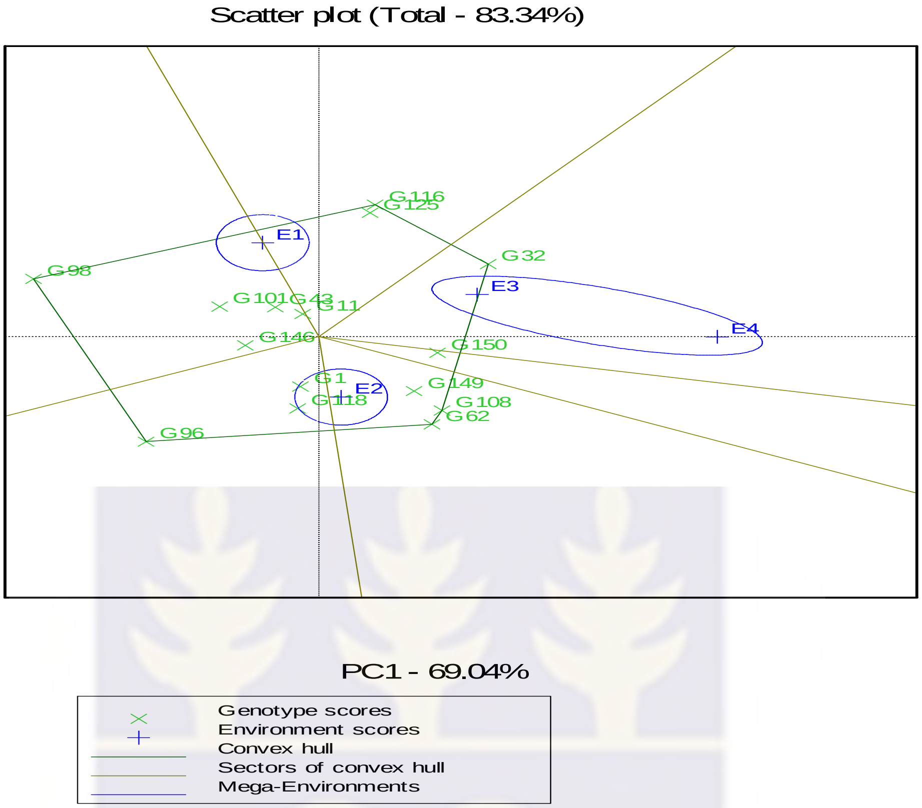

Figure 5-10 GGE biplots for days to 50 % maturity means

5.3.5. Grain Yield (Gyield)

A wide variability was observed among environments in terms of grain yield per plant (Figure. 5.11). E1 and E2 were the best environments since they recorded the highest mean grain yield per plant. Comparatively, the yield at E3 and E4 was very low. The largest yield variability was recorded at E1 followed by E4.

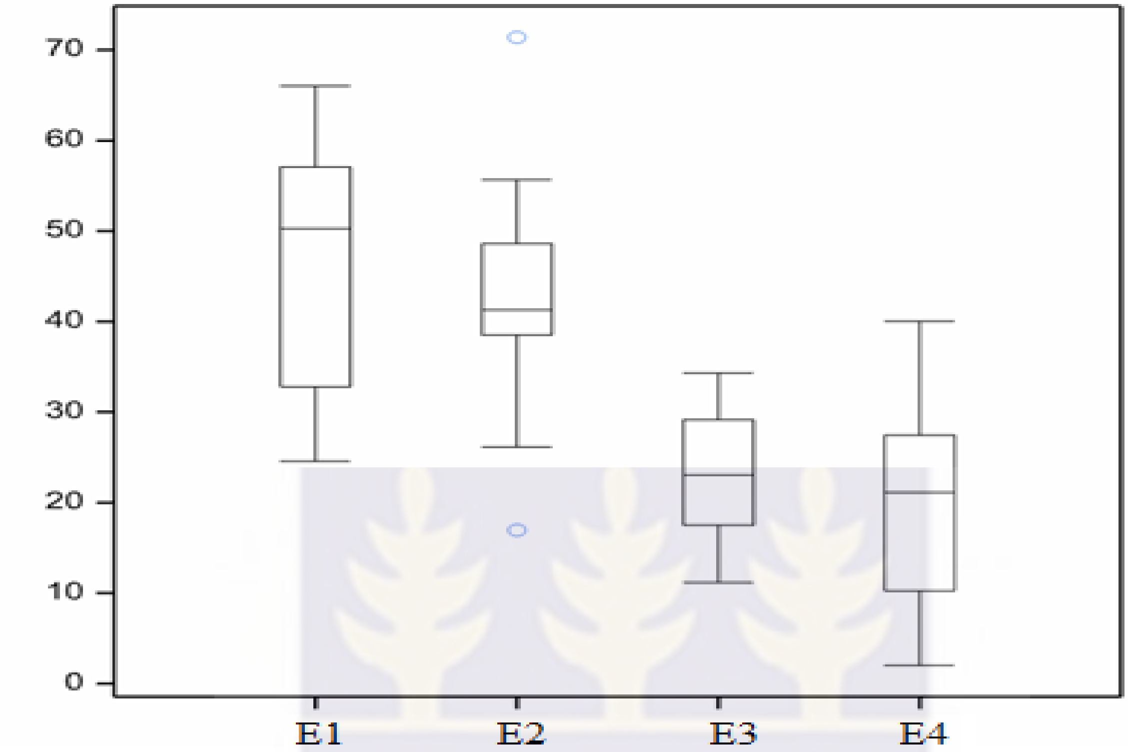

Figure 5-11 Boxplot for grain yield means per plant

With the general means of 48.33 and 20.35 g per plant, G118 and G98 were respectively the best and less performing cultivars (Table 5.9). G x E was not significant for grain yield, so the superior genotypes across the environments were G118, G150, G149, G108 and G62 with 48.23 g, 45.23 g, 40.32 g, 40.44 g and 39.03 g mean grain yield per plant. G118 was the winning cultivar at E1 and E2; however its performance decreased at E3 and E4. G150 was the most stable genotype as its yield was high at all the environments.

Table 5.9 Mean grain yield of genotypes across the environments

Code	Designation	E1	E2	E3	E4	Mean
G150	Jiraini	52.55	53.74	35.65	38.97	45.23
G125	Bonbohi	31.66	36.08	10.70	27.23	26.42
G11	Local chical	48.13	44.61	21.25	18.96	33.24
G96	Dan raha	31.77	24.74	21.33	16.67	23.63
G149	Waken chaibou	51.85	46.43	24.96	38.02	40.32
G116	Gnagaou	55.56	36.91	17.60	22.35	33.11
G98	Ndiambour	36.19	35.87	11.75	-2.42	20.35
G62	Dan baouchi	59.57	36.60	19.45	40.49	39.03
G101	Karadua	17.83	40.09	15.21	16.15	22.32
G146	Jan pass	33.24	43.29	32.64	15.43	31.15
G32	Matarka nawa	59.93	33.38	11.38	8.56	28.31
G1	Gorom local	59.59	33.35	34.53	7.67	33.78
G43	Farin wake	48.87	16.61	20.08	17.60	25.79
G118	Botsotua	71.60	76.52	27.69	17.11	48.23
G108	Tamalalo	38.70	57.06	31.99	34.00	40.44
Mean		**46.47**	**41.02**	**22.41**	**21.12**	**32.75**

E1 = Sadore rainy season 2016, E2 = Sadore dry season 2017, E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017.

5.3.6. Fodder yield (Fyield)

The boxplot for fodder yield means showed that E2 and E3 were the best environments (Figure 5.12). Very low fodder yield mean was observed at E4 due to severe striga infestation. The boxplot showed that the genotypes expressed largest variability at E2.

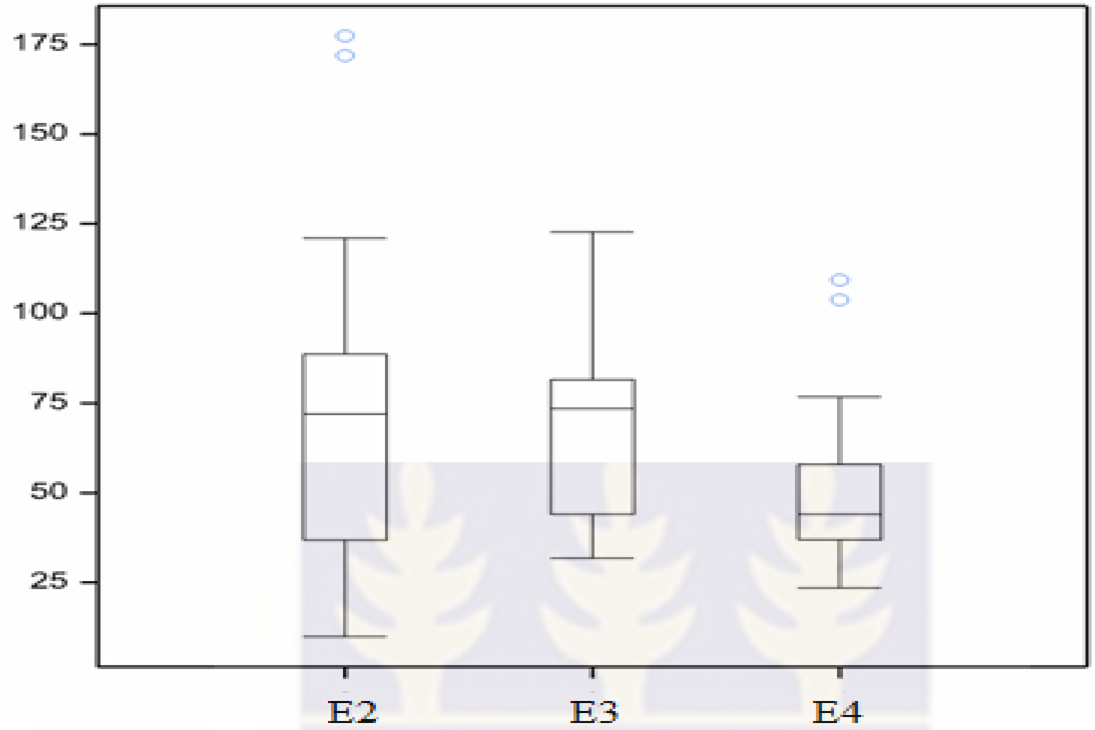

Figure 5-12 Boxplot for fodder yield means

Mean fodder yield of culivars across the environments varied from 31.24 to 121.42 g per plant. The superior genotypes were G197, G118 and G164 with respectively 121.42, 108.79 and 104.59 g per plant (Table 5.10). However, all the high fodder yielding varieties showed differential adaptation to environments. The widely adopted improved varieties were highly instable and low in fodder yield.

Table 5.10 Mean fodder yield of genotypes across the environments

Code	Genotype	E2	E3	E4	Mean	ASV
G149	Waken chaibou	68.45	70.78	58.58	65.94	1.45
G108	Tamalalo	90.17	84.83	79.45	84.82	1.46
G96	Dan raha	40.61	47.57	44.10	44.10	2.22
G32	Matarka nawa	40.22	72.02	33.82	48.69	2.78
G62	Dan baouchi	80.65	45.04	65.52	63.74	3.30
G150	Jiraini	88.85	68.33	60.88	72.69	3.50
G118	Botsotsuwa	123.72	89.65	112.99	108.79	3.63
G1	Gorom local	46.27	76.68	32.00	51.65	3.82
G101	Karadua	81.25	111.68	69.00	87.31	4.20
G98	Ndiambour	83.36	47.16	30.52	53.68	4.22
G43	Farin wake	20.61	36.07	42.33	33.00	4.70
G206	KVX	37.78	27.62	28.32	31.24	5.01
G209	TN-5-78	34.49	61.52	30.35	42.12	6.32
G197	NELOC-197	173.19	92.38	98.70	121.42	8.43
G205	IT90K-372-1-2	5.70	62.64	42.95	37.10	8.60
G164	NELOC-164	171.65	123.55	18.58	104.59	16.31
	Mean	**74.19**	**69.85**	**53.01**	**65.68**	

E2 = Sadore dry season 2017, E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017, ASV = AMMI Stability Value.

Environments were grouped into 2 mega-environments with E2 and E3 in one and E4 in the other. G164 and G197 were the winning genotypes at E2 and E3 while G118 was the best at E4 (Figure 5.13).

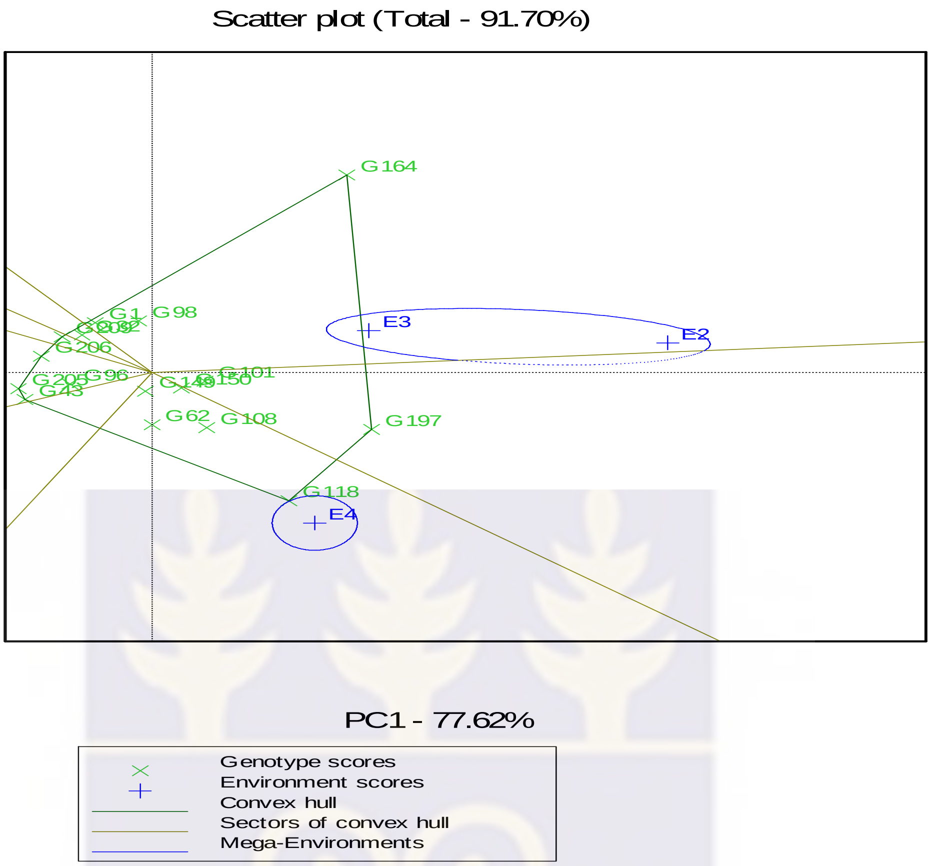

Figure 5-13 GGE biplots for fodder yield means

5.3.7. Pod yield (Pyield)

Pod yield per plant was higher at E3 in comparison to E4. Large variability among genotypes was however observed at E4 compared to E3. Mean pod yield per plant varied from 20.67 to 51.29 g per plant at E3 and from 2.45 to 71.76 g per plant at E4. The overall best genotypes were G62, G150 and G149 with 53.42, 49.38 and 45.84 g per plant, respectively. The least performing cultivars were G32, G98 and G101 as they recorded mean pod yield of 12.08, 16.93 and 19.68 g per plant, respectively (Table 5.11).

Table 5.11 Mean pod yield per plant of genotypes at E3 and E4.

Code	Genotype	E3	E4	Mean
G62	Dan Baouchi	35.08	71.76	53.42
G150	Jiraini	47.01	51.74	49.38
G149	Waken chaibou	43.07	48.62	45.84
G118	Botsotua	49.09	31.90	40.50
G108	Tamalalo	45.75	34.81	40.28
G1	Gorom local	51.29	24.47	37.88
G11	Local chical	30.25	43.96	37.10
G43	Farin Wake	39.19	32.87	36.03
G146	Jan Pass	48.43	16.37	32.40
G116	Gnagaou	28.16	35.01	31.59
G125	Bonbohi	21.32	35.70	28.51
G96	Dan Raha	39.30	17.19	28.24
G101	Karadua	21.59	17.77	19.68
G98	Ndiambour	31.42	2.45	16.93
G32	Matarka Nawa	20.67	3.48	12.08
	Mean	**36.78**	**31.21**	

E3 = Sadore rainy season 2017. E4 = Maradi rainy season 2017.

5.3.8. Seed number per pod (Snber)

There was a narrow variation among the environments with respect to number of seeds per pod. The mean per environment was 11.75 and 11.38 seeds per pod for E3 and E4, respectively. General mean number of seeds per pod varied from 9.43 to 12.48 with G62 having the highest and G98 the lowest mean. Variation among genotypes was larger at E4 than E3 (Table 5.12).

Table 5.12 Mean number of seeds per pod at E3 and E4

Code	**Genotype**	**E3**	**E4**	**Mean**
G62	Dan Baouchi	12.65	12.31	12.48
G149	Waken chaibou	11.34	13.03	12.19
G11	Local chical	12.22	12.14	12.18
G32	Matarka Nawa	12.36	11.79	12.08
G118	Botsotua	10.50	13.44	11.97
G116	Gnagaou	11.54	12.08	11.81
G146	Jan Pass	11.94	11.65	11.79
G96	Dan Raha	12.34	11.08	11.71
G150	Jiraini	11.33	12.02	11.67
G43	Farin Wake	12.04	11.13	11.58
G125	Bonbohi	10.81	12.17	11.49
G108	Tamalalo	12.30	10.59	11.44
G1	Gorom local	12.25	10.21	11.23
G101	Karadua	10.93	9.94	10.44
G98	Ndiambour	11.76	7.09	9.43
Mean		**11.75**	**11.38**	

E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017.

5.3.9. Pod length (Plength)

The two environments were similar in terms of pod length. E4 seemed to discriminate the cultivars better than E3. Genotypes with longest pods were G11 and G62. The pods of G98 were significantly shorter in comparison to those of the remaining genotypes (Table 5.13).

Table 5.13 Mean pod length for genotypes at E3 and E4

Code	Genotype	E3	E4	Mean
G11	Local chical	14.52	15.61	15.06
G62	Dan Baouchi	15.04	15.05	15.05
G149	Waken chaibou	14.46	15.38	14.92
G125	Bonbohi	14.98	14.34	14.66
G150	Jiraini	14.41	14.87	14.64
G108	Tamalalo	15.03	14.14	14.59
G43	Farin Wake	14.24	14.69	14.47
G118	Botsotua	13.37	15.37	14.37
G116	Gnagaou	14.18	14.51	14.34
G1	Gorom local	14.77	12.72	13.74
G96	Dan Raha	14.00	13.12	13.56
G146	Jan Pass	13.31	13.82	13.56
G101	Karadua	13.22	12.79	13.00
G32	Matarka Nawa	11.41	12.79	12.10
G98	Ndiambour	12.90	8.78	10.84
	Mean	**13.99**	**13.87**	**13.93**

E3 = Sadore rainy season 2017. E4 = Maradi rainy season 2017.

5.3.10. Harvest index (HI)

Mean harvest index was higher at E4 than E3 meaning that the cultivars produced more grain than fodder at the latter than the former. The overall mean HI was 0.41. The mean per genotype ranged from 0.12 to 0.49 with G149 having the highest mean and G101 the lowest. Genotypes that were best in grain and fodder production were G149, G150, G43 and G62. Those suited for fodder production were G101, G32 and G116 (Table 5.14).

Table 5.14 Mean harvest index of genotypes at E3 and E4

Code	**Designation**	**E3**	**E4**	**Mean**
G149	Waken chaibou	0.66	0.32	0.49
G150	Jiraini	0.48	0.45	0.46
G43	Farin wake	0.40	0.50	0.45
G62	Dan baouchi	0.49	0.40	0.44
G11	Local chical	0.18	0.56	0.37
G96	Dan raha	0.21	0.51	0.36
G108	Tamalalo	0.41	0.31	0.36
G146	Jan pass	0.14	0.53	0.33
G118	Botsotsuwa	0.27	0.28	0.27
G1	Gorom local	0.19	0.32	0.26
G116	Gnagaou	0.24	0.17	0.20
G98	Ndiambour	0.10	0.29	0.20
G32	Matarka nawa	0.08	0.20	0.14
G101	Karadua	0.15	0.08	0.12
Mean		**0.37**	**0.45**	**0.41**

E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017.

5.3.11. Threshing percentage (Thresh %)

The two environments did not differ from one another in terms of threshing percentage. The mean across genotypes was 61.9 %. It varied from 56.39 % in G101 to 70.53 % G149 (Table 5.15).

Table 5.15 Mean threshing percentage of genotypes at E3 and E4

Code	Designation	E3	E4	Mean
G149	Waken chaibou	63.72	77.33	70.53
G150	Jiraini	68.57	65.27	66.92
G118	Botsotsuwa	61.20	71.37	66.29
G11	Local chical	71.03	56.59	63.81
G62	Dan baouchi	66.66	58.85	62.76
G43	Farin wake	59.82	65.19	62.50
G146	Jan pass	68.54	54.96	61.75
G108	Tamalalo	55.06	67.55	61.31
G96	Dan raha	70.19	50.88	60.53
G32	Matarka nawa	60.87	59.42	60.15
G116	Gnagaou	53.81	63.11	58.46
G1	Gorom local	65.30	51.42	58.36
G98	Ndiambour	55.36	58.34	56.85
G101	Karadua	54.54	58.23	56.39
Mean		**62.48**	**61.32**	**61.90**

E3 = Sadore rainy season 2017, E4 = Maradi rainy season 2017.

5.4. Discussion

The highly significant differences detected among genotypes for almost all studied traits indicated the existence of large genetic diversity in the germplasm under investigation. Similar findings in cowpea were reported by El-shaieny *et al*. (2015) and Teixeira *et al*. (2007). The significant variation observed between environments implied that the weather factors differed widely according to year and location. Major climatic determinants for plant productivity are moisture, temperature, light, carbon dioxide and daylength (White and Howden 2010). Available weather data for E1, E2 and E3 suggested relative humidity and solar radiation as the main causes of variation observed between environments. The mean available phosphorus of 6.42 ppm and 5.20 ppm for E1 on one hand and E2 and E3 on the other showed that these sites did not vary significantly in terms of soil available P content. In the case of E4, the rainfall was the only available weather data and it was similar to that of the other sites. Genotype by environment interaction occurs when environments are not correlated or the genotypic variance is heterogeneous or both conditions are present (Crossa *et al*., 1993; 2004). The detection of significant G x E for days to flowering, days to 50 % maturity, fodder yield, pod yield, harvest index and threshing percentage in the present work was an indication of the occurrence of at least one of the conditions cited above. Significant G x E interactions for days to flowering, days to maturity, pod and seed weight per plant was observed by Aliyu and Makinde (2016).The lack of significant genotype by environment interactions in terms of grain yield per plant revealed by the current study was not consistent with Santos *et al.* (2015) who reported significant G x E interactions for grain yield while studying the adaptability and stability of cowpea cultivars to Midwest Brazil areas. Significnat G x E for grain yield were also observed by Omoigui *et al*. (2017) who used biplots analysis to assess the performance of cowpea varieties under striga infestation in the dry agro-ecology of Nigeria. Similar results were reported by Santos *et al.* (2017) following three years stability evaluation of erect cultivars in Mato Grosso do Sul state of Brazil. Furthermore, Nwofia *et al.* (2016) found both significant year by genotype and planting date by genotype interactions regarding seed yield per ha in soybean, but they detected only year by genotype interactions in terms of number of seed per plant.

The medium to high contribution of genotypes to the variation in days to flowering and fodder yield implied that selection for these traits can be carried out successfully. However, the gain in selection may be low, especially regarding days to flowering since the environmental contribution to its variation was also high. G98 was the best genotype for early flowering; however it was not stable and can therefore be recommended for use in rainy seasons at Sadore and Maradi where it performed well. The results showed that the large variation recorded by shoot dry weight has no genetic basis; it was mainly affected by the environment. Shoot dry weight was high in rainy seasons and very low in dry season, the only environmental factors that varied significantly between rainy and dry season were the relative humidity and solar radiation according to the weather data, these climatic factors may therefore be the cause of the observed slow seedlings growth that resulted in low shoot dry weight in the dry season. No information was available to explain the very high dry shoot weight obtained at Maradi compared to the other environments. That site could be relatively higher in available P content compared to the remaining test environments and according to Ansah *et al.* (2014) shoot dry weight was the most sensitive trait to P deficiency.

The yield is usually known to be highly influenced by environmental conditions. The high environmental influence on yield (pod, grain and fodder) detected in the present work was in agreement the findings of Aliyu and Makinde (2016). It was also consistent with Omoigui *et al.* (2017) and Santos *et al.* (2015) who respectively reported that the environment was responsible for 35.01and 78.27 % of the variation observed in grain yield of cowpea. However dissimilar results were detected by Baraki *et al*. (2014) who working on sesame found that the genotypes contribution (37.3 %) to yield variation was greater than that of the environments (29.5 %). The environment contribution to the variation was higher in grain yield than fodder in the present study. However, in both traits, the genotypes accounted for sizeable part of the variation giving thereby room for selection of superior genotypes. The dimension of experimental plot could have affected grain yield as the present results showed that the grain yield per plant was higher in trials with small plots compared to those with large plots area.

The similarity detected among test environments by the GGE biplots analysis in terms of grain yield per plant could be the reason why significant G x E interaction was not detected for that trait. However despites the absence of GEI, a change in ranking of genotypes was observed as

G118 which was best at E1 and E2 was not the leading cultivar at E3 and E4, revealing differential adaptation of some genotypes to environments.

P deficiency in soils caused stunted growth and low yield, therefore genotypes with high grain and/or fodder yield on such conditions could be considered as tolerant. In the present work, G150 and G149 recorded high grain yield, G101 produced high fodder while G118 and G108 were good in both grain and fodder yield. These cultivars were therefore considered as adapted to P deficient soil conditions. The overall mean harvest index of 41% obtained in this study implied that most of the lines under study were good in both grain and fodder. It was however greater in comparison to the value of 34.5 % reported by Rajput. 1994.

High striga infestation occurred at E4 and it significantly affected both grain and fodder yield of susceptible varieties. E4 recorded the highest mean shoot dry weight however it had the lowest mean fodder yield; this is an indication of striga damage on some varieties. Sampling for shoot dry weight determination was made at 8 weeks DAP, the fact that striga negative impact was not detected on that trait indicated that the parasite damage on susceptible varieties occurred after 8 weeks DAP. Therefore, scoring for striga tolerance at 8 weeks DAP or earlier may not give reliable results and this observation was in agreement with Singh and Emechebe (1997) who recommended scoring at 9 weeks DAP. According to these findings, the yield of cowpea extra-early cultivars may not be significantly affected by striga. Some of the tested genotypes had expressed high level of tolerance to striga. Positive association between striga infestation and field fertility status was reported. Zouera *et al*. (2016) stated that low fertile soils are more prone to striga infestation in comparison to fertile fields. Since farmers' fields, especially in Niger are predominantly poor, cowpea varieties that tolerate both striga and low P soil conditions could be the most adequate alternative for yield improvement. According to our results, G150, G118, G108, G149 and G62 had some good level of tolerance to both low P soil and striga could be therefore used as varieties or sources of genes for improvement of elite varieties. Apart from tolerating both striga and low P soils, G150 had a stability of 0.6, thereby cumulating high performance and stability. This finding did not corroborate with Amara and Suale (1996) who identified IT86D-1010 and IT86D-716 as most P efficient cowpea varieties but only adapted to high rainfall areas of Sierra Leone. However, high seed yield per plant and stability were detected in Cream 7, Azmerly, Blackeye crowder, Dokii and Black crowder genotypes by El-Shaieny *et al.* (2015).

The overall mean seed number per pod of 11.57 obtained in this work was higher than the mean of 6.33 reported by Inuwa *et al.* (2012) but lower than that of 13.2 found by Rajput, (1994). The non-significant G x E interaction revealed by our results regarding seeds number per pod and pod length was not in agreement with Gerano *et al. (*2015) who detected significant GEI in these traits.

5.5. Conclusion

The results showed that both the genotypes and environments were significantly different for most of the traits under study. However, G x E interaction was only significant for days to flowering, days to 50 % maturity, fodder yield harvest index, pod yield and threshing percentage. The contribution of genotypes to the variation was high regarding fodder yield and days to flowering, but medium in terms of grain yield. Genotypes with high grain and fodder yield under low P soil conditions were detected, nevertheless, only G150 was highly stable across the test environments. Cultivars tolerant to both low P soil conditions and striga were also identified. Candidate Genotypes for release as variety were identified.

CHAPTER 6

6.0. Effects of planting date on the cycle and yield of local cowpea varieties in Niger

6.1. Introduction

Genotype interaction with temperature, photoperiod and other factors of the environment affects the duration of vegetative and reproductive growth phases of grain legumes causing a reduction in yield (Summerfield. 1980; Hadley *et al.*, 1983). High temperatures during long days cause two or more weeks delay in flowering in many cowpea genotypes (Warrag and Hall. 1983). Heat susceptible genotypes loose the five first flowers on its main stem following two weeks or more of successive or interrupted hot nights in the first four weeks after germination (Ahmed *et al.*, 1992). However the negative impact of heat on the yield of many crops is affected by photoperiod (Hall, 1992) while temperature in turn moderates sensitivity to photoperiod (Vince-Prue, 1975). The effects of both heat and photoperiod on grain legume crops may be influenced by planting date. According to Azari and Khajepour, (2003), planting date is among the main factors that affect the growth and yield of leguminous crops. The same authors asserted that planting date is responsible for the positive correlation occuring between plant phenological stage and climatic factors. In soybean many studies were conducted to find out the effects of planting date on grain yield and its components. Alghamdi (2004) tested five soybean genotypes in six planting dates during 2000 and 2001 years and observed significant sowing date by genotype interactions with regard to seed weight per plant and grain yield per hectare. Similar findings were reported by Nwofia (2016); ElHerty *et al.* (2010); Kandil *et al.* (2012); Ngalamu *et al.* (2013) and Bello *et al.* (1996). Also May *et al*. (1989) affirmed that the yield advantage of early maturing soybean cultivars over late maturing ones was influenced by planting date. The use of unsuitable planting dates was cited among the factors that bring about low yield in cowpea

(Coetzee, 1990; Singh *et al.*, 2002; Ishiyaku *et al.*, 2005). In an attempt to determine the appropriate sowing date of cowpea in Northwest and Limpopo provinces (South Africa), Shiringani *et al.* (2007) tested 10 cowpea genotypes in three planting dates. They reported November 8th as best date for grain yield across the locations. In contrast, using the same cowpea genotypes, the same planting dates and the same locations, Shiringani and Shimelis, (2011) identified December 6th as most adequate planting date for high grain yield. Dhital *et al.* (1997) stated that early planting gave higher seed yield compared to late sowing. In Ghana, six cowpea varieties were evaluated in six planting dates (Ansoba *et al.*, 2013), the results showed that appropriate sowing date varied with variety, the authors however recommend early planting to take advantage of more suitable weather conditions and less insect damage. Planting date determines the time that the plant will flower. Late planting of early maturing varieties prevents farmers from getting the benefit of early harvests (Fatokun *et al*., 2002). Cowpea varieties have been classified into different maturity groups namely extra-early, early, medium and late maturing, but it should be noted that the cycle of many cultivars is subject to the environmental influence. Day length interaction with genotype may prolong or shorten the phenological cycle of photoperiod sensitive varieties with subsequent effect on its yield. In Niger, the adoption of improved cowpea varieties is very low; majority of farmers are still growing local varieties which are known to be mostly sensitive to photoperiod. Day length varies from 12h 55 min in June (the beginning of rainy season) to 11h 50 min in October (the end of the season) in Niger (*https://planificateur.a-contresens.net/heure/NE-niger.html)*. Other environmental factors such rainfall, temperatures and relative humidity vary continuously throughout the cropping season. Under these conditions, planting date may considerably affect the cycle, yield and yield components of photosensitive cultivars. The identification of adequate planting dates of cowpea, especially local farmer varieties may significantly improve cowpea yield in small scale farmers' field in Niger. The objectives of the present work were to:

- assess the effect of planting dates on the cycle, grain and fodder yield of some local varieties in Niger;
- determine the best planting dates for high grain and/or fodder yield of farmers' cowpea varieties;
- identify cultivars adapted to early and late planting conditions.

6.2. Materials and methods

6.2.1. Sites

The experiments were conducted at ICRISAT Sadore and Ndounga experimental station of INRAN. All the locations are located around Niamey and share approximately the same climatic conditions. Niamey is situated in the Sahelian zone where the mean winter (December, January, and February) temperature is 25.3°C and mean spring (March,April and May) temperature is 32.7°C.

Sadore is located at 45 km in the south of Niamey and lies on latitude 13°14'N and longitude 2°16'E and is located at an altitude of 235 m above sea level. Mean annual rainfall between 1983 and 2015 was 556.92 mm with the peak in August (ICRISAT unpublished).

Ndounga is at 20 km in the south east of Niamey. It is located on latitude 13°22' N and longitude 2°14' E at an altitude of 217 m. Annual rainfall ranged from 495.5 to 610.8 mm between 2013 and 2017 with a mean of 561.6 mm.

6.2.2. Agro-climatic data

Large difference was observed between Kollo and Sadore in terms of the amount of rainfall. The overall rainfall quantities received was 482.1 and 572.4 mm respectively at Kollo and Sadore. The amount of rainfall was higher at Sadore than Kollo in all the wet season months except September (Table 6.1)

Table 6.1 Rainfall data of the experimental sites

Month	Kollo	Sadore
June		
Decade1	1.00	16.9
Decade2	58.5	18.6
Decade3	17.5	49.5
July		
Decade1	70.00	78.1
Decade2	34.5	67.9
Decade3	59	40.6
August		
Decade1	74.10	76.8
Decade2	13	85.7
Decade3	62.7	40.0
September		
Decade1	22.80	24.8
Decade2	40	27.4
Decade3	29	46.1
Total	**482.1**	**572.4**

The only available climatic data at Kollo was rainfall, however for Sadore; data were obtained on air and soil temperature, relative humidity, solar radiation, evaporation and wind speed (Table 6.2). Mean evaporation and wind speed were considerably higher in June compared to other months. Mean minimum and maximum air and soil temperatures were also slightly higher in June. However mean minimum and maximum relative humidity were lower in June, reached the peak in August and dropped in September.

Table 6.2 Weather data of Sadore in 2016

Month	Evap.	Min TP	Max TP	HUM-07	HUM-13	SOLAR	ST05-07	ST05-13	ST10-07	ST10-13	WIND
June											
Dec1	8.2	26.4	38.2	69	40	19.0	29.8	47.7	31.4	39.3	5.0
Dec2	7.4	26.9	37.1	71	43	-	29.5	45.9	30.3	38.7	5.5
Dec3	5.3	25.1	34.0	80	60	-	29.0	40.0	29.8	35.2	3.3
Mean	**7.0**	**26.1**	**36.4**	**73**	**48**	-	**29.4**	**44.5**	**30.5**	**37.7**	**4.6**
July											
Dec1	5.2	25.1	34.7	84	57	-	28.1	41.1	28.9	36.1	3.8
Dec2	4.3	23.8	32.9	90	67	-	26.9	38.6	27.7	33.9	3.4
Dec3	3.9	24.3	32.6	90	66	20.9	26.6	38.7	27.6	33.2	2.7
Mean	**4.5**	**24.4**	**33.4**	**88**	**63**	-	**27.2**	**39.5**	**28.1**	**34.4**	**3.3**
August											
Dec1	4.5	24.1	32.0	89	70	19.5	26.6	35.7	27.4	31.3	3.1
Dec2	3.6	22.9	31.8	95	68	19.3	25.5	35.8	26.1	31.8	2.3
Dec3	4.4	23.4	33.0	94	66	20.7	26.3	40.2	27.4	35.2	3.0
Mean	**4.2**	**23.5**	**32.3**	**93**	**68**	**19.8**	**26.1**	**37.2**	**27.0**	**32.8**	**2.8**
Sept.											
Dec1	3.7	23.1	32.4	92	64	16.8	26.6	40.3	27.8	34.7	2.0
Dec2	4.6	23.8	34.6	89	56	21.9	27.3	43.3	28.3	37.0	2.5
Dec3	4.3	23.3	34.4	91	59	20.1	26.7	41.8	27.9	36.9	1.9
Mean	**4.2**	**23.4**	**33.8**	**90**	**60**	**19.6**	**26.9**	**41.8**	**28.0**	**36.2**	**2.1**

Key: Dec = decade. Evap. = evaporation; Min TP = minimum temperature. Max TP = maximum temperature. HUM-07= min relative humidity. HUM-13 = maximum relative humidity. SOLAR = solar radiation. ST05-07 = min soil temperature at 5 cm depth. ST05-13 = max soil temperature at 5 cm depth. ST10-07 = min soil temperature at 5 cm depth. ST10-13 = max soil temperature at 10 cm depth

6.2.3. Germplasm

A total of twenty one local cowpea varieties collected from the crop major growing areas in Niger were used for the study (Table 6.3)

Table 6.3 List of cowpea genotypes used for the study

ENTRY_NO	NAME	TYPE	Village	Region	Maturity (Farmers)
G16	Dan Illa INRAN	Improved	INRAN		
G33	Dan Batsatsa	Local	Kornaka	Maradi	80
G34	Bougou Bougou	Local		Zinder	NA
G35	Dan Dam	Local	Dan Saga	Maradi	100
G36	Tcheto	Local	Tcheto	Dosso	60
G37	Tessa	Local	Tessa	Dosso	90
G38	Bagagi 21 ans	Local	Bagagi	Dosso	NA
G45	Gouma	Local	Gouma	Dosso	>90
G46	Dan Bawada Daji	Local	Bawada Dadji	Dosso	90
G47	El Danke	Local	Maitsakoni	Maradi	80
G51	Farin wake	Local	Matankari	Dosso	early
G54	Salga Sabongari	Local	Salga	Dosso	medium
G56	Dan Mangaza	Local	Wangarawa	Maradi	NA
G59	Darey kiota	Local	Darey	Dosso	NA
G63	Arnen wake	Local	Matankari	Dosso	NA
G69	Gnagaou	Local	Lido	Dosso	NA
G71	Hwarin wake	Local	Kornaka	Maradi	90
G74	Baadare	Local	Karanguiya	Maradi	75
G78	Lakade	Local	Maiki	Maradi	NA
G80	Dan Baourota	Local	Kornaka	Maradi	80-90
G58	Dan Bekori	Local	Bekori	Zinder	NA

6.2.4. Method

The trials were carried out in 2016 and 2017. A total of six planting dates were used.

The first, second and third 2016 experiments were planted on 30th June, 19th July and 3rd August 2016 at ICRISAT Sadore. Seeds were sterilized with Thioral (25 % Hyperchlor, 25 % Thirame) prior to planting. Four seeds were planted per hill and thinned to 2 plants per hill at 21 days after planting (DAP). Alpha lattice design with 2 replications was used. Each genotype was planted each in two rows of 6 m long with a spacing of 1m inter and 0.5 m intra. Borders lines were planted 1m apart from the first row on each side of the field. Only one weeding was done at 3 weeks DAP, later weeds were controlled when necessary by uprooting manually. Insects were controlled by chemical application; however no insecticide was effective with regard to *Clavigralla tomentosicollis.*

The 2017 trials were conducted at INRAN experimental station of Ndounga. The first and second plantings were carried out on 7th and 22nd July respectively while the last one was sown on 5th August. Experimental design was alpha lattice with 2 replications. Seeds were treated with fungicide before planting. Four seeds were sown and thinned to 1 plant per hill at 3 weeks after planting. The plot was 2.6 m long and 2 m wide. Within the plot, the spacing was 0.5 m intra and 0.8 m inter rows. Distance between plots was 1.5 m. Borders lines were planted 1.5 m apart the first rows. Weeding was carried out twice. The field was treated three times with insecticide.

Data were collected on agronomic and yield parameters as follow:

- shoot dry weight (SDWt): Plants were uprooted from four hills in each plot at 8 weeks after planting, dried at room temperature and weighed;
- plant height (PHt): The tallest two plants selected randomly per plot were measured using a tape measure at 8 week after planting;
- days to flowering (DAF) : number of days from planting to first flower appearance;
- days to 50 % maturity (MAT50): number of days from planting to 50 % maturity;
- grain yield per plant (Gyield): dry seeds weight per plot divided by the number of plants per plot.

For 2017 trial, additional data were collected on the following parameters:

- fodder yield per plant (Fyield) : dry fodder weight per plot divided by the number of plants per plot;

- pod yield (Pyield) : dry pods weight per plot divided by the number of plants per plot;
- hundred seed weight (HSWt).
- pod length (Plength). the lenght of three normal dry pods per plot was measured with a ruler;
- number of seeds per pod (NSPd): the number of seeds contained in three normal dry pods per plot was determined;

The field was infested by striga; the genotypes were therefore scored for tolerance to the parasite according to a modified rating scale of Singh and Emechebe (1997). The scale was as follow:

- 1. Resistant: no Striga emergence on the plot and no Striga symptoms observed on plants.
- 2. Tolerant: Several Striga emergences but no significant yield reduction.
- 3. Moderately resistant: few Striga emergence (2-3) per plot but no Striga symptoms observed on the plants.
- 4. Scusceptible: Five to several Striga plants emerged per plot and plants showed severe Striga symptoms.
- 5. Several Striga plants emerged per plot and most of the plants have died.

The data were subjected to combined analysis of variance using SAS 9.4 sofware. AMMI which has on one hand, an additive component accounting for genotype and environment main effects and on the other, a multiplicative terms that models G x E was performed to study the patterns of G x E and to determine differential adaptation of genotypes to environments. The model is as follow:

$$Yij = \mu + Gi + Ej + \sum_{k=1}^{k} \lambda \boldsymbol{k} Y + \epsilon_{ij}$$

The GGE (G plus GxE) biplots which is similar to AMMI except that the multiplicative terms include the genotypic main effect in addition to GE was run to:

- directly identify the best performing genotypes
- determine the mega environments (group of environment with common best performing genotypes). The winning genotype for a mega-environment is the vertex cultivar at the intersection of the two polygon sides whose perpendicular lines form the boundary of that environment.

Test environment with longer vectors are the ones that discriminate the genotypes better; if the environment has a short vector, it means the performance of all the genotypes is similar within that environment; the difference between cultivars cannot therefore be detected.

The representativeness of the environments is determined according to the angle formed by the environment and the average environment coordination (AEC), tests environments that have small angle with AEC are more representative than the ones having large angle.

Both AMMI and GGE biplots analysis were carried out using Genstat 12 statistical software.

Percentage contribution of IPCA1, IPCA2 and the residual to the G x E variation as well as the contribution of genotypes, environment, G x E and the error to the total variation observed in each trait were determined as in chapter five.

AMMI sum of squares was partitioned in its different components only for traits where the two IPCA were significant. GGE biplots analysis was not done for shoot dry weight because there were no significant interaction between genotypes and environments with regard to that trait.

The data of days to flowering were not analyzed because of missing data. For days to 50 % maturity, only the data of five planting dates instead of six were used in the analysis. In the last planting date of 2017 many genotypes were not able to reach 50 % maturity because of drought and *Clavigralla tomentosicollis* damage.

6.3. Results

Signficant differences were detected among genotypes with regard to grain yield, plant height, days to 50 % maturity and fodder yield. Genotypes were not significantly different for shoot dry weight and number of seeds per pod. However, environments were significantly different for all the traits. Significant genotype by environment interaction was observed in grain yield, fodder yield, plant height and days to 50 % maturity (Table 6.4 and 6.5).

Table 6.4 Mean squares of traits (combined ANOVA using six planting date's data)

	Mean square			
Source	**Gyield**	**PHt**	**SDWt**	**MAT50**
Env	11302.79***	17902.97***	25167.94***	2386.49***
Genotype	1573.24***	3371.55***	375.88	205.72***
Rep(Env)	185.21	20238.46***	1803.61***	7.17
BLOCK(Rep)	129.72	2641.48*	729.55*	12.41
Env*Genotype	352.04***	1330.73	271.42	24.40***
Error	122.12	1054.70	274.09	4.72

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield.

Table 6.5 Mean squares of traits (AMMI analysis)

	Mean square						
SOV	**Gyield**	**Fyield**	**Height**	**SDWt**	**MAT50**	**Plength**	**Snumber**
Genotypes	1870***	8666***	3948***	449ns	261.5***	13.81***	12.52**
Environments	11778***	87472***	18059	27232***	2480.2***	76.07**	292.89***
Block	192ns	7524***	18075***	1635***	9.3ns	9.91*	19.11*
Interactions	391***	2396**	1625*	291ns	27.4***	5.24ns	4.55ns
Error	123	1160	1173	309	5.1	3.49	5.01

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, ns = non significant.

Planting dates were significantly different for all the traits both in 2016 and 2017. But in 2017, no significant difference was detected for striga infestation. Genotypes were also significantly different for traits within each of the two years except for shoot dry weight and number of seeds per pod (Table 6.6 and 6.7).

Planting date by genotype interaction was detected for days to flowering, days to 50 % maturity, grain yield, fodder yield and striga infestation (Table 6.7).

Table 6.6 Mean squares of traits (combined ANOVA using 2016 planting dates' data)

	Mean square				
SOV	DAF	PHt	Gyield	MAT50	SDWt
Planting date	2597.73***	6299.84*	1348.67***	4908.38***	2091.51***
Genotype	165.56***	2774.95*	1348.67***	128.28***	119.00ns
Rep(Env)	18.01ns	41698.42***	27.87ns	5.91ns	1028.84***
Block(Rep)	16.45ns	3271.52*	55.77ns	3.99ns	196.15ns
Env*Genotype	21.23*	1111.24	110.94*	23.15***	76.28ns
Error	12.62	1278.81	59.23	3.28	121.78

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, ns = non significant.

Table 6.7 Mean squares of traits (combined ANOVA using 2016 planting dates' data)

	Mean square							
SOV	**PHt**	**Gyield**	**MAT50**	**SDWt**	**Striga**	**Plength**	**Snber**	**Fyield**
Planting date	16850.82***	24208.73***	129.81***	6400.33***	0.21ns	65.15***	264.34***	87472.12***
Genotype	2614.02*	1284.52***	128.00***	602.21ns	4.36***	9.42**	8.57ns	6637.03***
Rep(Env)	1817.39ns	500.42ns	11.16ns	1878.17*	0.26ns	12.60*	20.07*	7113.24ns
Block(Rep)	1566.16ns	128.13ns	13.11ns	718.36ns	0.52*	2.89ns	1.15ns	1906.61**
Env*Genotype	1697.32ns	508.49***	15.45*	418.28ns	0.37*	4.86ns	3.59ns	1936.48*
Error	1168.59	190.43	6.01	418.28	0.21	3.63	5.89	1038.45

DAF =days to flowering, MAT50 = days to 50 maturity, PHt = plant height, SDWt = shoot dry weight, Gyield = grain yield, striga = striga damage scores, Plength= pod length, Snber = number of seeds per pod, Fyield = Fodder yield, ns = non significant.

The interaction components namely IPCA1 and IPCA2 were significant for grain yield, plant height, days to 50 % maturity and fodder yield. They accounted for 86.11, 65.72, 87.04 and 100 % of the G x E variation observed in grain yield, plant height, days to 50 % maturity and fodder yield, respectively. In all these traits, IPCA1 explained the major part of the G x E variation (Table 6.8). The residual contribution to GEI was only high (34 %) with respect to plant height.

Table 6.8 Contribution of the interaction components to G x E variation

PCA components	Gyield	PHt	Fyield	MAT50
IPCA1	70.59	37.99	57.63	60.93
IPCA2	15.52	27.74	42.37	26.11
Residuals	13.89	34.28	0.00	12.95
Total	100.00	100.00	100.00	100.00

MAT50 = days to 50 maturity, PHt = plant height, Gyield = grain yield, Fyield = fodder yield

The partitioning of the AMMI sums of square into its different components indicated that genotypes had a medium contribution to the total variation detected in yield and yield components. Genotypes contribution was low with regard to agronomic traits except days to 50 % maturity. However the environments were responsible for the largest part of the variation observed in all the traits. The error term contribution was high in plant height, pod length and number of seeds per pod (Table 6.9).

Table 6.9 Partitioning of total AMMI sum of squares into its different components

SOV	Gyield	PHt	SDWt	Fyield	MAT50	Plenght	Snber
Genotypes	23.89	13.12	3.81	31.70	26.67	32.32	18.06
Environments	42.61	36.70	68.81	38.03	59.78	23.63	51.54
Interactions	24.96	27.00	12.35	17.53	11.16	24.52	13.14
Error	8.54	23.18	15.03	12.73	2.39	19.51	17.25
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Genotypes contributed 42.83 and 24.69 % to the total variation observed in grain yield in 2016 and 2017, respectively. Planting date contribution to grain yield variation amounted to 16.92% in 2016 and 45.85 % in 2017. The variation in days to 50 % maturity in 2016 was mainly caused by planting date (72.98 %) while genotypes accounted for 18.74 %. Genotype by planting date interactions accounted for 28.5 % and 20.35 % to grain yield variation in 2016 and 2017, respectively. The interaction contributed 6.96 % to days to 50 % maturity variation in 2016.

6.3.1. Days to 50 % maturity (MAT50)

A significant reduction in the phenological cycle was observed in all the genotypes following the comparison of the number of days to flowering and days to 50 % maturity of the 2016 first and last planting dates. All the varieties took more days to start flowering or to reach 50 % maturity when planted at the beginning of the season compared to when planting was carried out late. The mean number of days to flowering of the first sowing overpassed that of the third sowing by 16.08 days. The mean difference between the two planting dates with regard to days to flowering ranged from 11.43 in G59 to 30.21 days in G34. The difference between the two planting dates was even larger with respect to days to 50 % maturity. The mean days to 50 % maturity of the third sowing date was 21.18 days lower than that of first sowing. It varied from 15.41 in G80 to 33.86 days in G34 (Table 6.10).

Table 6.10 Comparison of the 2016 mean days to flowering and days to 50 % maturity of the first and last planting dates

Code	**Designation**	**DAF1**	**DAF2**	**DIFF**	**MAT1**	**MAT2**	**DIFF**
16	Dan Illa INRAN	54.52	39.72	14.80	87.39	63.66	23.72
33	Dan Batsatsa Kornaka	51.28	39.60	11.68	80.89	61.40	19.48
34	Bougou Bougou	75.55	45.35	30.21	98.64	64.78	33.86
35	Dan Dam Ali neino	60.85	45.35	15.49	98.71	66.93	31.77
36	Tcheto Dan kassari	53.05	41.28	11.76	82.99	66.39	16.60
37	Tessa Abdoulaye mai goshi	62.08	43.76	18.33	86.54	65.98	20.56
38	Bagagi 21 ans	51.26	37.10	14.16	79.48	61.90	17.58
45	Gouma Sami Godje	53.30	40.56	12.74	79.31	64.78	14.53
46	Dan Bawada Daji	58.85	42.42	16.43	81.78	65.07	16.71
47	El Danke Maitsakoni	73.92	50.60	23.32	-	-	-
51	Farin wake Matankari	53.30	43.35	9.95	78.31	62.21	16.10
54	Salga Sabongari	54.72	38.80	15.92	79.29	62.81	16.48
56	Dan Mangaza Wangarawa	55.60	42.57	13.03	78.40	62.39	16.02
59	Darey kiota est	54.28	42.86	11.43	84.89	65.87	19.02
63	Arnen wake Matankari	54.08	39.42	14.66	83.54	63.57	19.98
69	Gnagaou Lido	55.52	41.08	14.44	85.39	66.04	19.34
71	Hwarin wake kornaka	52.85	40.85	12.01	84.43	61.71	22.73
74	Baadare Karanguiya	68.02	44.56	23.46	100.46	67.78	32.68
78	Lakade Maiki	74.43	48.44	25.98	100.73	70.97	29.76
80	Dan Baourota kornaka	51.06	39.36	11.70	78.78	63.37	15.41
Mean		**58.42**	**42.35**	**16.08**	**85.79**	**64.61**	**21.18**

DAF1 = days to flowering of the first planting date. DAF2 = days to flowering of the last planting date. MAT1 = days to 50 % maturity of the first planting date. MAT2 = days to 50 % maturity of the first planting date. DIFF = mean of the first planting date minus that of the last planting date.

Mean days to 50 % maturity was 72.77 and ranged from 64.56 to 86.06 days after planting. The highest and the lowest means were observed at E1 and E3 respectively. The mean number of days to 50 % was 86.06, 67.40 and 64.56 for first, second and third planting dates in 2016. In 2017, the means were 74.11 and 71.73 for the first and second planting dates respectively. The earliest and latest maturing cultivars were G51 and G78 in 2016 while in 2017, the first genotype to reach maturity was G80 and the last was G74. Across the environments, G80 was the earliest maturing genotype with a mean of 67.27 days to 50 % maturity. Late maturing cultivars were

G74, G34, G78 and G35 with the means of 84.13, 82.15, 80.06 and 79.98 days to 50% maturity, respectively. The most stable and early maturing genotype was G63 which recorded an overal mean of 70.50 days to 50 % maturity and a stability value of 0.1 (Table 6.11).

Table 6.11 Mean days to 50 % maturity and stability values of genotypes across the environments

Code	Genotype	E1	E2	E3	E4	E5	Mean	ASV
G63	Arnen wake	83.51	65.26	62.47	73.01	68.26	70.50	0.1
G71	Hwarin wake	84.26	63.26	62.76	73.76	67.26	70.26	0.9
G38	Bagagi	79.15	63.51	62.65	71.15	69.01	69.10	1.1
G46	Bawada	81.26	65.27	63.97	71.26	70.27	70.41	1.3
G51	Farin wake	77.97	63.27	63.26	73.47	68.27	69.25	1.3
G56	Dan mangaza	78.97	64.14	63.51	70.47	67.27	68.87	1.3
G16	Danila	87.59	61.97	63.47	73.09	69.97	71.22	1.5
G33	Dan Batsatsa	80.77	65.97	61.59	68.27	68.97	69.11	1.5
G54	Salga	78.33	64.77	62.47	68.83	70.27	68.94	1.6
G59	Darey	84.77	67.51	66.01	69.27	70.51	71.62	1.8
G69	Gnagaou	85.33	68.64	65.27	69.33	72.76	72.27	1.9
G36	Tcheto	83.90	67.97	66.27	71.90	74.97	73.00	2.0
G80	Dan baourota	78.52	63.02	63.26	65.52	66.02	67.27	2.4
G37	Tessa	85.77	69.91	65.65	68.77	68.65	71.75	2.5
G34	Bougou bougou	97.65	79.47	65.76	87.15	80.69	82.15	3.1
G78	Lakade	100.90	79.64	70.09	75.90	73.76	80.06	3.6
G35	Dan dam	100.01	67.91	66.02	86.51	79.47	79.98	5.3
G74	Baadare	100.33	71.64	67.52	96.33	84.83	84.13	7.6
Mean		**86.06**	**67.40**	**64.56**	**74.11**	**71.73**	**72.77**	

E1 = first planting date in 2016. E2 = second planting date in 2016. E3 = last planting date in 2016. E4 = first planting in 2017. E5 = second planting date in 2017. E6 = last planting date in 2017, ASV = AMMI Stability Value.

The test environments fell into two mega-environments with different winning genotypes. G78 was the best cultivar in the first mega-environment which was composed of E2 and E3 while G74 won in the second, which is made up of E1, E4 and E5 (Figure 6.1).

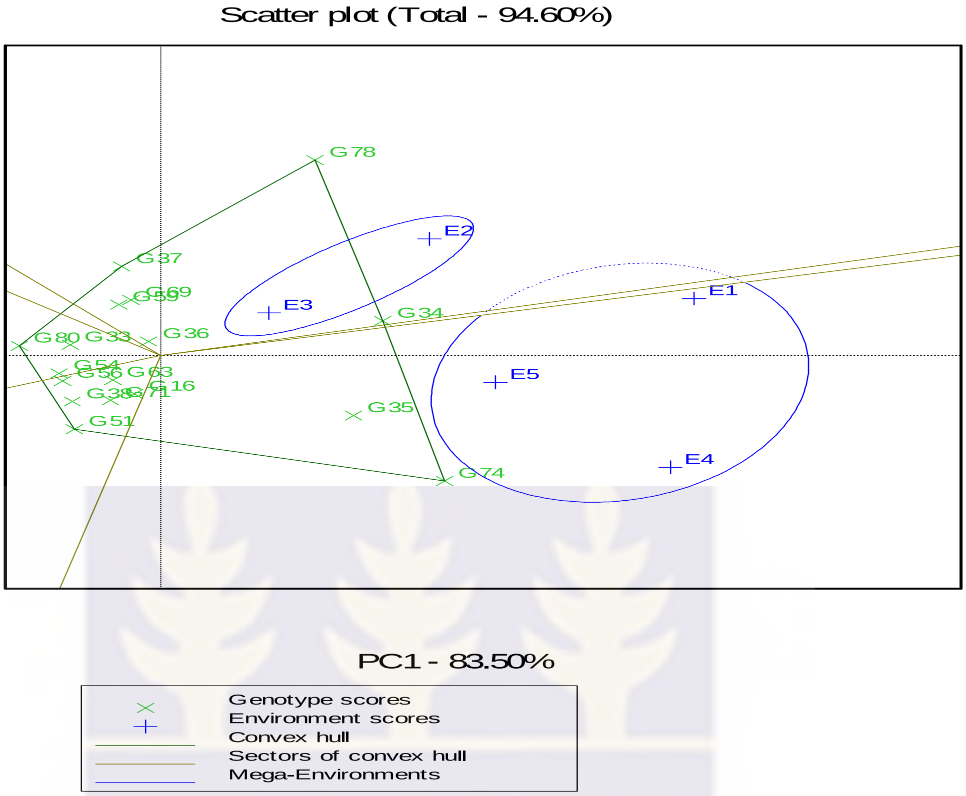

Figure 6-1 GGE biplots of days to 50 % maturity

E1 and E4 had similar power in discriminating genotypes as their vectors had approximatively the same length. However, E1 was most representative since it had smaller angle with PCA1 which explained the largest part of the variation (83.5 %) (Figure 6.2).

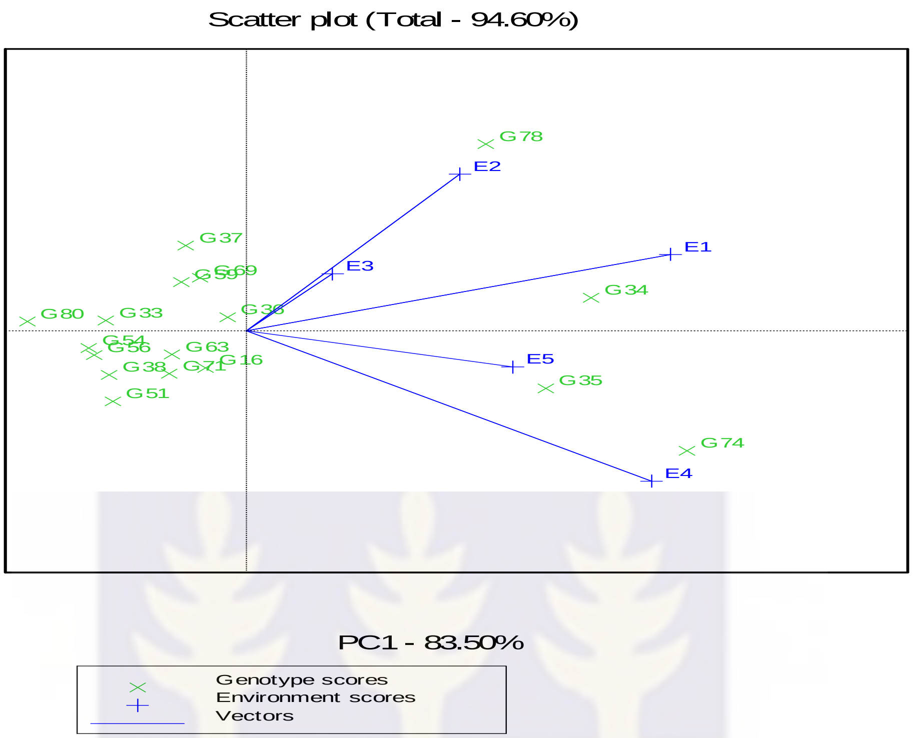

Figure 6-2 Discriminating power and representativeness of the environments

6.3.2. Grain yield (Gyield)

Table 6.12 shows the results for grain yield per plant over all test environments. Mean grain yield varied from 11.67 to 58.15 g per plant with the highest recorded at E4 and the lowest at E6. The mean grain yield was 23.35, 15.94 and 12.67 g per plant for the first, second and third planting date in 2016 respectively. It was 58.15, 19.75 and 11.67 g per plant for planting date1, 2 and 3 in 2017. The best performing genotypes in 2016 were G63 and G33 while in 2017; the winning genotypes were G54, G59 and G56. G63, G33 and G71 produced highest grain yield for planting date1, 2 and 3 respectively in 2016. In 2017, G54 won in sowing date1 whereas G59 and G56 were the superior cultivars in date2 and 3 respectively. All the genotypes except G34, G35, G36 and 37 produced higher grain yield at E4 in comparison to the other environments. The first planting dates recorded the highest mean grain yield in both 2016 and 2017 while the lowest belonged to last planting dates. G56 and G34 were the best and worse performing genotypes, respectively with 40.47 and 1.78 g grain yield per plant across the test environments. Other lines with high grain yield were G33, G59, G54, G63 and G38. Genotypes G34, G35, G78, G74 and G47 had lowest performance across the environments. Higher grain yield was obtained in 2017 compared to 2016. All the high yielding cultivars were not stable. The most stable genotype was G46 which had an ASV of 0.2 and a mean of 24.04 g per plant.

Table 6.12 Mean grain yield per plant and stability values of genotypes across test environments

Code	Genotype	E1	E2	E3	E4	E5	E6	Mean	ASV
G56	Dan mangaza	32.78	28.95	26.67	95.65	30.77	28.02	40.47	8.5
G33	Dan Batsatsa	32.60	45.67	13.57	79.33	44.24	16.36	38.63	5.6
G59	Darey	26.62	19.58	24.09	104.17	34.90	20.21	38.26	15.8
G54	Salga	35.55	7.99	20.41	120.21	16.36	22.36	37.15	21.2
G63	Arnen wake	63.88	23.67	19.53	64.77	24.27	15.18	35.22	4.8
G38	Bagagi	37.34	17.97	14.74	84.42	33.61	16.83	34.15	8.4
G71	Hwarin wake	24.96	29.38	38.35	62.86	24.54	14.23	32.39	1.6
G80	Dan baourota	22.70	27.49	9.99	93.05	6.01	16.30	29.26	14.6
G51	Farin wake	32.84	24.73	19.49	69.55	3.94	12.51	27.18	2.4
G16	Danila	40.63	17.59	8.11	44.37	34.96	3.87	24.92	6.8
G46	Bawada	23.12	23.74	11.98	58.45	11.49	15.49	24.04	0.2
G69	Gnagaou	20.63	7.96	11.94	53.12	26.42	5.56	20.94	2.2
G47	Eldanke	3.31	-0.23	0.89	78.31	18.53	10.89	18.62	10.6
G36	Tcheto	29.84	12.79	3.84	17.33	9.23	-1.39	11.94	13.7
G78	Lakade	2.57	2.49	2.43	31.96	9.79	9.46	9.78	6.3
G74	Baadare	3.10	3.48	2.90	26.04	13.15	6.48	9.19	9.1
G37	Tessa	8.12	6.57	6.16	10.40	13.64	1.30	7.70	15.4
G35	Dan dam	4.90	0.83	3.51	10.46	13.33	6.46	6.58	15.9
G34	Bougou bougou	-1.85	2.22	2.17	0.49	6.06	1.57	1.78	16.7
Mean		**23.35**	**15.94**	**12.67**	**58.15**	**19.75**	**11.67**	**23.59**	

E1 = first planting date in 2016. E2 = second planting date in 2016. E3 = last planting date in 2016. E4 = first planting in 2017. E5 = second planting date in 2017. E6 = last planting date in 2017, ASV = AMMI Stability Value.

The results showed that two mega-environments were formed. The first was composed of E1, E2, E3 and E5 and had G63 as the winning genotype. The second consisted E4 and E6 and the best performing cultivar was G54 (Figure 6.3).

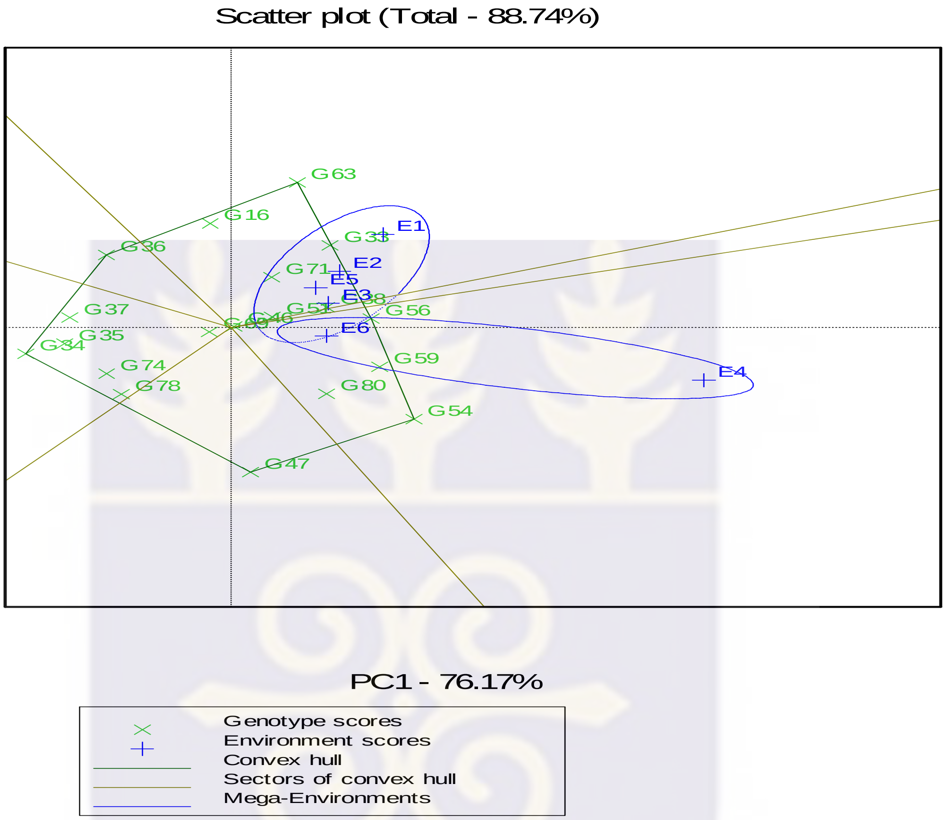

Figure 6-3 GGE biplots of grain yield per plant

E4 was the most discriminating environment as it had the longest vector along the PC1 which accounted for 76.17 % of the yield variability; it also had the smallest angle with that principal component axis, hence most representative among test environments (Figure 6.4).

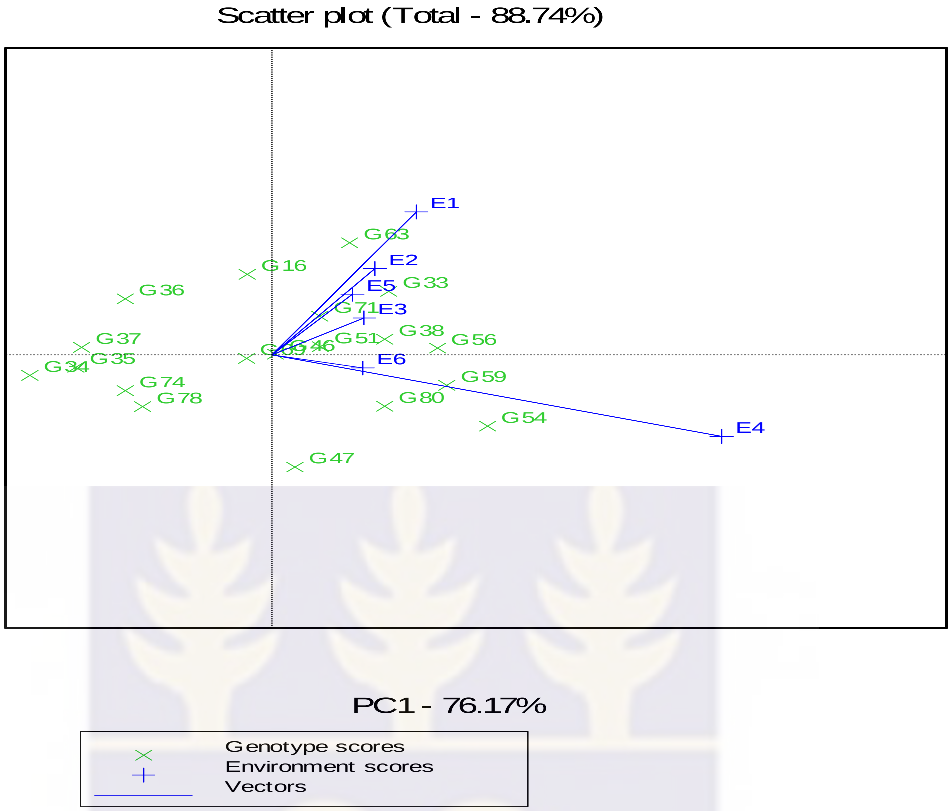

Figure 6-4 Discriminating power and representativeness of environments

6.3.3. Shoot dry weight (SDWt)

Lower shoot dry weight was obtained in 2016 compared to 2017. It varied from 26.20 to 86.57 g per plant across the environments. In 2017, planting date1 and 2 recorded significantly higher shoot dry weight in comparison to the last planting date. In contrast, the last planting date recorded higher shoot dry weight compared to the two first sowing dates in 2016. The overall mean was 54.99 per plant. The best performance was observed in G56 (66.40 g) while G59 had the least (40.84 g). None of the lines was stable as the stability values ranged from 1.3 to 7.8 (Table 6.13).

Table 6.13 Mean shoot dry weight per plant and stability values of genotypes across test environments

Code	Genotype	E1	E2	E3	E4	E5	E6	Mean	ASV
G56	Dan mangaza	27.37	18.44	41.39	130.24	102.43	78.55	66.40	6.7
G47	Eldanke	22.12	36.31	47.21	109.29	87.25	78.36	63.42	3.8
G51	Farin wake	16.93	37.66	42.51	127.39	93.76	56.31	62.43	7.8
G34	Bougou bougou	41.09	47.74	50.01	97.12	75.10	57.45	61.42	3.9
G74	Baadare	29.63	27.71	52.24	69.37	112.75	67.68	59.90	7.4
G69	Gnagaou	29.50	30.11	53.06	73.91	92.86	63.87	57.22	5.0
G78	Lakade	30.30	27.21	32.30	111.35	80.67	59.93	56.96	4.6
G36	Tcheto	31.94	29.54	31.63	84.01	91.22	63.79	55.36	1.9
G35	Dan dam	28.43	35.53	26.46	86.00	75.86	77.15	54.90	3.1
G71	Hwarin wake	14.27	36.78	62.33	74.97	92.55	45.69	54.43	2.1
G54	Salga	12.49	32.30	36.22	92.17	92.05	60.09	54.22	2.8
G63	Arnen wake	38.18	23.22	44.01	60.92	85.02	71.89	53.87	5.9
G33	Dan Batsatsa	28.45	41.12	30.07	61.36	82.66	76.49	53.36	4.7
G46	Bawada	23.07	28.65	36.22	100.76	70.55	59.39	53.11	4.2
G37	Tessa	25.25	33.00	45.19	74.54	78.18	57.62	52.30	1.3
G38	Bagagi	33.03	29.59	35.52	63.20	70.17	61.49	48.83	4.7
G16	Danila	17.22	30.20	41.36	73.72	67.26	58.30	48.01	1.6
G80	Dan baourota	21.52	19.85	25.92	75.93	92.80	51.01	47.84	2.7
G59	Darey	27.05	21.59	28.92	78.52	46.70	42.26	40.84	2.8
Mean		**26.20**	**30.87**	**40.14**	**86.57**	**83.67**	**62.49**	**54.99**	

E1 = first planting date in 2016. E2 = second planting date in 2016. E3 = last planting date in 2016. E4 = first planting in 2017. E5 = second planting date in 2017. E6 = last planting date in 2017, ASV = AMMI Stability Value.

6.3.4. Plant height (PHt)

The environments of 2017 recorded higher plant height compared to those of 2016 (Figure 6.5). The means varied from 137.49 to 216.82 cm across the environments. Higher plant height was observed in all the genotypes at E5 except G33 and G35. Within the years, the second planting date recorded highest plant height. G34 was the cultivar with the highest mean plant height across the environments while G16 had the lowest. There was re-ranking of genotypes among environments resulting in low stability (Table 6.14).

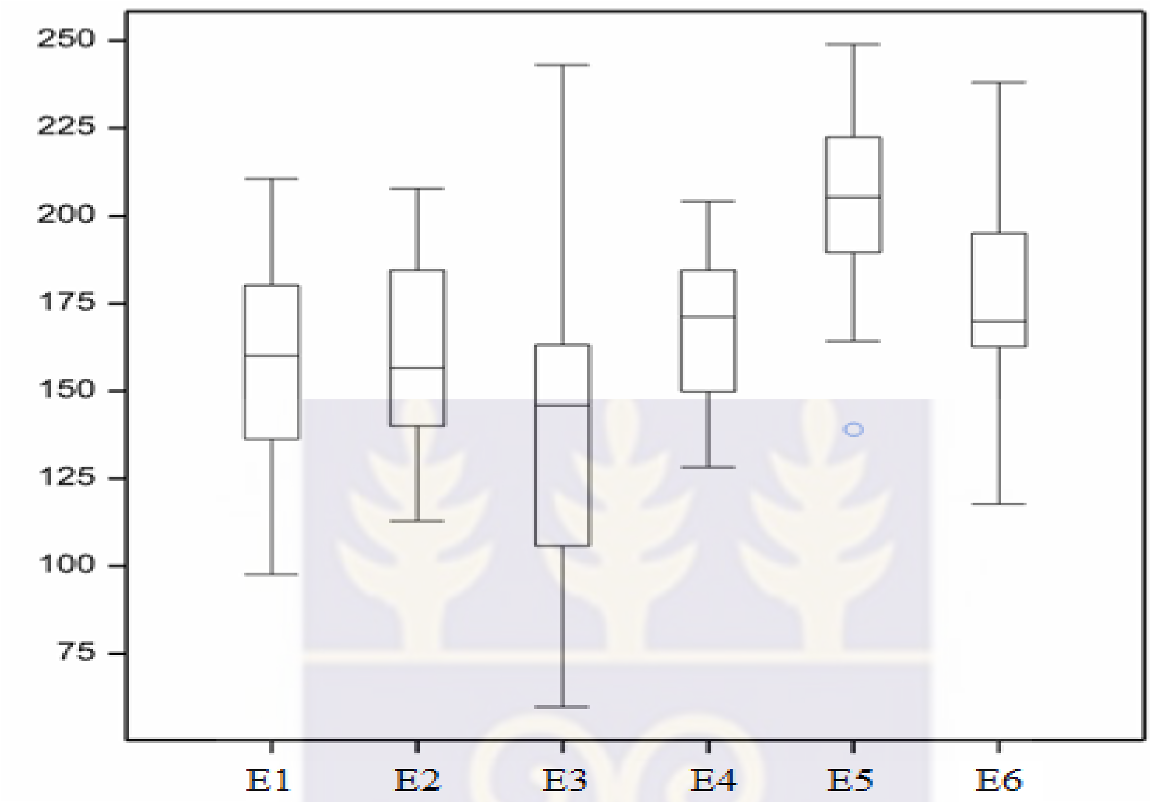

Figure 6-5 Boxplot for plant height means

Table 6.14 Mean plant height and stability values of genotypes across test environments

Code	**Genotype**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**Mean**	**ASV**
34	Bougou bougou	195.59	224.04	229.87	199.67	243.04	208.70	216.82	5.8
54	Salga	135.77	148.63	135.21	186.35	262.63	260.71	188.21	8.8
36	Tcheto	169.10	186.46	163.46	138.35	204.71	212.63	179.12	3.4
37	Tessa	184.06	200.34	148.41	173.81	192.84	168.74	178.03	3.9
51	Farin wake	139.54	179.88	134.68	207.96	208.88	179.34	175.05	4.6
78	Lakade	180.28	131.20	172.74	178.45	195.20	173.74	171.94	2.0
47	Eldanke	111.93	148.68	167.15	198.10	202.68	201.90	171.74	5.4
38	Bagagi	157.82	172.78	140.81	159.09	215.03	180.15	170.95	1.4
74	Baadare	165.23	139.71	161.35	173.15	213.96	152.60	167.66	2.4
46	Bawada	148.20	176.06	125.10	187.20	194.81	174.60	167.66	2.4
59	Darey	178.13	181.42	157.42	177.13	184.67	106.42	164.20	4.8
56	Dan mangaza	100.31	142.13	100.15	211.10	228.79	191.49	162.33	9.7
69	Gnagaou	158.87	126.34	153.90	140.04	213.84	175.31	161.39	1.2
63	Arnen wake	180.40	138.42	120.27	141.81	192.42	185.60	159.82	3.8
71	Hwarin wake	170.78	187.20	100.34	152.03	190.20	150.09	158.44	3.4
35	Dan dam	157.18	154.04	141.94	133.09	140.04	176.28	150.43	6.5
33	Dan Batsatsa	182.96	126.85	80.98	142.13	174.35	192.90	150.03	5.7
80	Dan baourota	164.18	118.10	73.59	157.35	224.60	143.92	146.95	5.0
16	Danila	124.87	149.35	117.54	126.79	173.60	132.79	137.49	1.7
Mean		158.17	159.56	138.15	167.56	202.96	177.26	167.28	

E1 = first planting date in 2016. E2 = second planting date in 2016. E3 = last planting date in 2016. E4 = first planting in 2017. E5 = second planting date in 2017. E6 = last planting date in 2017, ASV = AMMI Stability Value.

Three meg-environments were formed with the first containing E1, the second containing E2 and E3 and the last was composed of E4, E5 and E6. G59 was the winning cultivar at E1, G34 won at E2 and E3 while the winning genotypes in the last mega-environment were G54 and G56 (Figure.6.6).

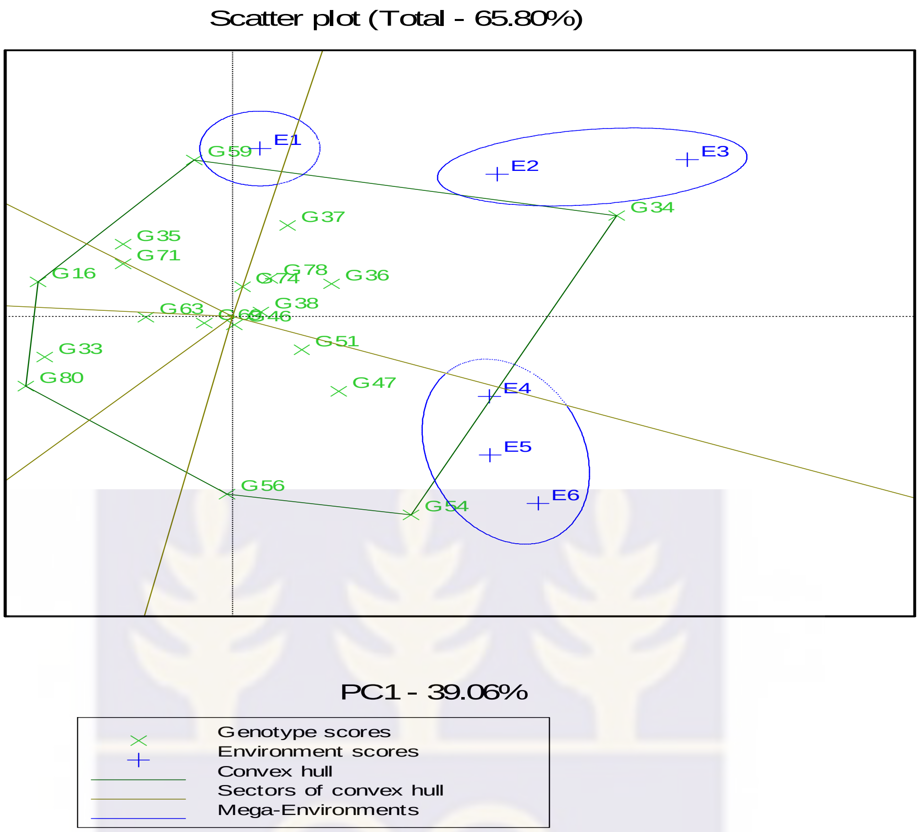

Figure 6-6 GGE biplots for plant height

The scatter biplot explained only 69.8 % of the plant height variation. E3, E5 and E6 discriminated genotypes better than the remaining environments in terms of plant height; however E3 was the most discriminating representative among test environments as it had the longest vector and formed the smallest angle with PC1 axis (Figure 6.7).

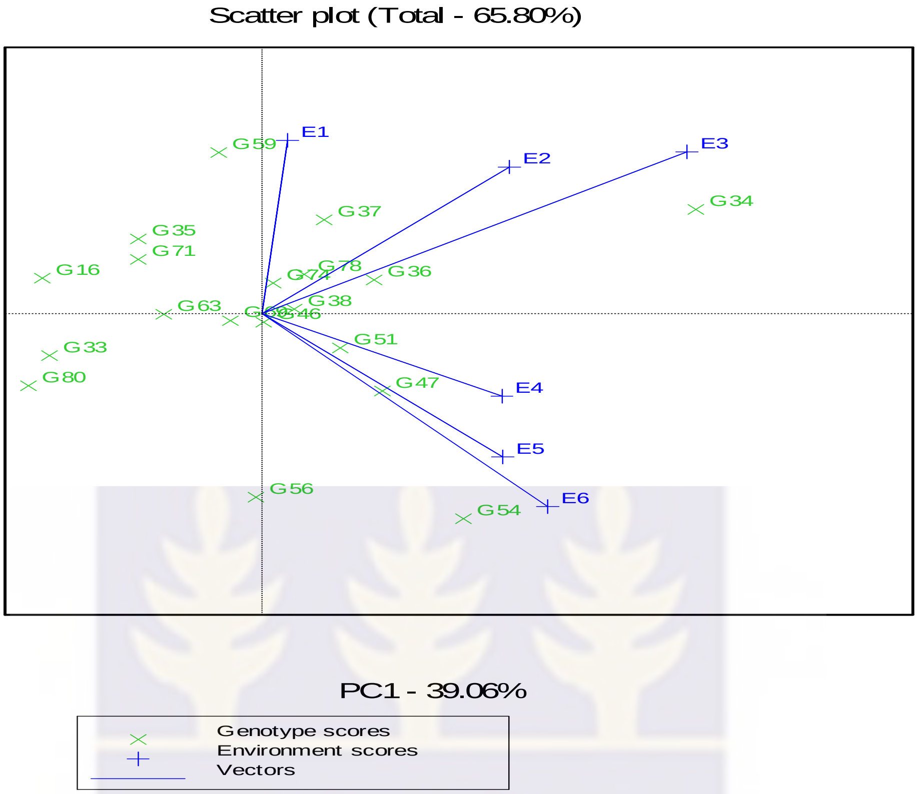

Figure 6-7 Discriminating power and representativeness of environments

6.3.5. Pod length (Plength)

Table 6.15 shows the mean pod length per genotype. The pod length showed low variability between planting dates as it ranged from 9.55 (E6) to 12.26 cm (E4). The mean across the first, second and third sowing dates was 10.76 cm. The longest and shortest pods were observed in G59 and G34 with respectively 12.96 and 6.12 cm. G59 was the winning genotype at all the test environments since G x E was not significant.

Table 6.15 Mean pod length of genotypes across the 2017 planting dates

Code	Genotype	E4	E5	E6	Mean
59	Darey	16.04	13.85	8.99	12.96
46	Bawada	13.26	10.20	13.93	12.46
33	Dan batsatsa	13.76	12.25	10.83	12.28
78	Lakade	12.73	11.79	11.66	12.06
74	Baadare	15.03	7.89	11.60	11.51
71	Hwarin wake	13.19	11.14	9.71	11.35
56	Dan mangaza	14.35	10.95	8.61	11.30
80	Dan baraouta	13.40	12.83	7.37	11.20
58	Dan bekori	10.91	12.52	10.09	11.17
38	Bagagi21	14.34	9.12	9.30	10.92
37	Tessa	12.03	10.46	10.19	10.89
51	Farin wake	11.69	12.06	8.88	10.87
54	Salga	14.01	9.32	8.98	10.77
35	Dan dam	12.64	9.91	9.51	10.69
63	Arnen wake	11.03	9.63	8.30	9.65
36	Tcheto	11.09	9.67	7.90	9.55
69	Gnagaou	9.99	10.36	8.11	9.49
16	Danila	9.35	7.93	10.17	9.15
34	Bougou bougou	4.00	6.98	7.39	6.12
Mean		**12.26**	**10.47**	**9.55**	**10.76**

E4 = first planting, E5 = second planting date, E6 = last planting date.

6.3.6. Seed number per pod (Snumber)

Large variability was observed among planting dates regarding number of seeds per pod. Significantly higher seeds per pod were obtained at the first planting date than the two other environments. The number of seeds per pod at sowing date1 (8.80) was more than two folds that of sowing date3 (3.63). The overall mean number of seeds per pod was 5.62. G59 recorded the highest mean while G34 had the lowest (Table 6.16).

Table 6.16 Mean number of seeds per pod of genotypes across 2017 planting dates

Code	**Genotype**	**E4**	**E5**	**E6**	**Mean**
59	Darey	10.97	8.38	4.25	7.87
33	Dan batsatsa	10.22	7.12	4.25	7.20
71	Hwarin wake	10.69	6.42	4.06	7.06
54	Salga	10.28	4.64	5.35	6.76
80	Dan baraouta	9.82	5.32	5.08	6.74
58	Dan bekori	8.25	6.46	5.24	6.65
56	Dan mangaza	10.61	6.26	2.66	6.51
38	Bagagi21	9.53	4.23	5.25	6.34
37	Tessa	9.84	5.11	3.20	6.05
16	Danila	7.27	4.12	5.34	5.58
51	Farin wake	8.94	4.14	3.28	5.45
74	Baadare	11.38	0.73	3.40	5.17
78	Lakade	8.71	2.20	4.23	5.05
46	Bawada	8.75	4.72	1.48	4.98
63	Arnen wake	7.51	4.25	3.11	4.95
35	Dan dam	8.39	2.01	2.36	4.25
36	Tcheto	7.97	2.27	1.72	3.99
69	Gnagaou	5.52	3.68	2.68	3.96
34	Bougou bougou	2.55	2.09	2.09	2.24
Mean		**8.80**	**4.43**	**3.63**	**5.62**

E4 = first planting in 2017, E5 = second planting date in 2017, E6 = last planting date in 2017.

6.3.7 Fodder yield (Fyield)

The first and second planting dates were the most favorable environments for fodder production as they recorded significantly higher means than the third date (Figure 6.8). The fodder means were respectively 149.36, 139.95 and 64.07 g per plant for sowing date2, date1 and date3. The mean fodder yield across the environments was 117.19 g per plant. Superior genotypes were G35, G78 and G74 with 178.50, 173.63 and 167.37 g per plant. The cultivars with least performance were G58, G34 and G38 with a yield of 49.34, 73.84 and 74.72 g respectively. All the high yielding genotypes were not stable. G36 was a medium yielding and most stable genotype (ASV = 0.8) (Table 6.17).

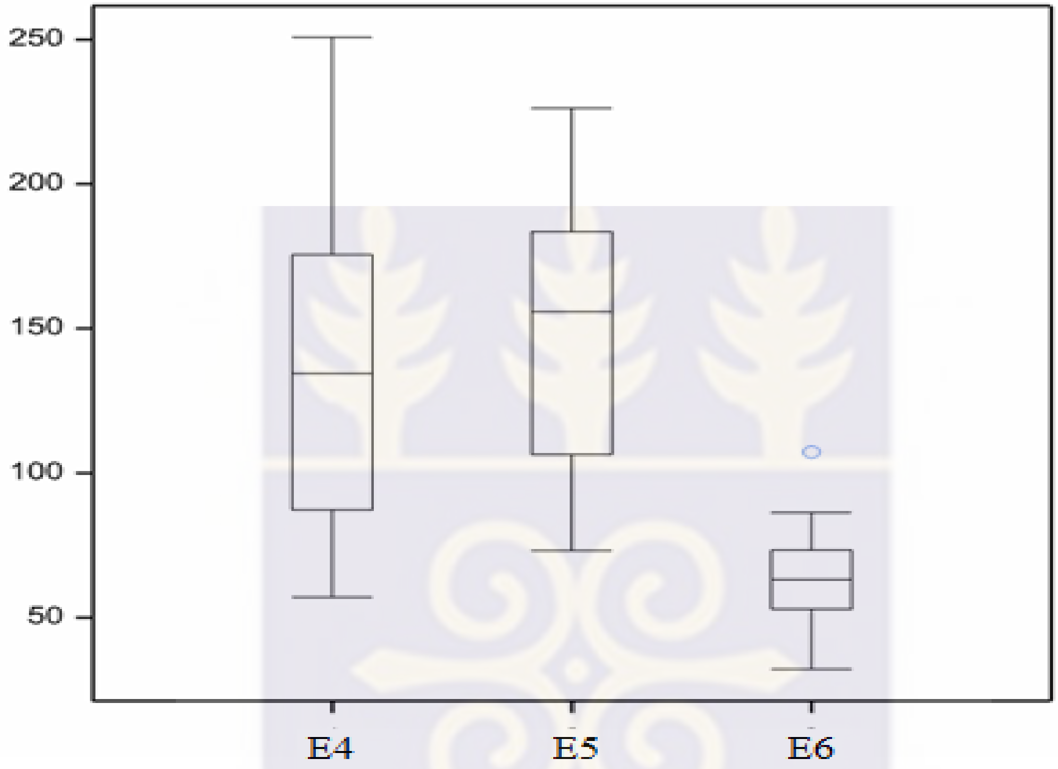

Figure 6-88 Boxplot for fodder means per plant

Table 6.17 Mean fodder yield per plant and stability values of genotypes across 2017 planting dates

Code	**Genotype**	**E4**	**E4**	**E6**	**Mean**	**ASV**
35	Dan dam	251.75	185.44	98.30	178.50	7.9
78	Lakade	222.27	215.09	83.52	173.63	7.1
74	Baadare	229.90	197.24	74.98	167.37	5.0
37	Tessa	175.53	214.23	66.10	151.95	5.6
51	Farin wake	183.35	180.49	52.04	138.63	2.5
46	Bawada	156.88	165.53	88.19	136.87	3.8
47	Eldanke	206.00	102.06	80.51	129.52	5.6
63	Arnen wake	119.59	191.43	76.32	129.11	4.1
36	Tcheto	152.69	159.44	59.09	123.74	0.8
69	Gnagaou	129.24	166.42	59.44	118.36	3.3
71	Hwarin wake	134.23	168.60	43.76	115.53	3.5
56	Dan mangaza	155.85	136.89	52.55	115.10	2.0
54	Salga	110.82	150.65	74.60	112.02	3.2
80	Dan baourota	114.35	127.63	51.90	97.96	0.5
16	Danila	72.05	113.66	107.54	97.75	7.5
59	Darey	115.18	101.90	45.34	87.47	2.0
33	Dan Batsatsa	72.06	111.32	70.04	84.47	5.0
38	Bagagi	61.10	108.48	54.57	74.72	4.3
34	Bougou bougou	83.17	130.66	7.66	73.83	3.7
58	Dan bekori	53.01	60.04	34.98	49.34	6.8
Mean		139.95	149.36	64.07	117.79	

E4 = first planting. E5 = second planting date. E6 = last planting date, ASV = AMMI Stability Value.

The environments were grouped into two mega-environments. The first contained E5 and had G78 as winning cultivars. The second was made up of E4 and E6 and G35 was the best performing line (Figure.6. 9).

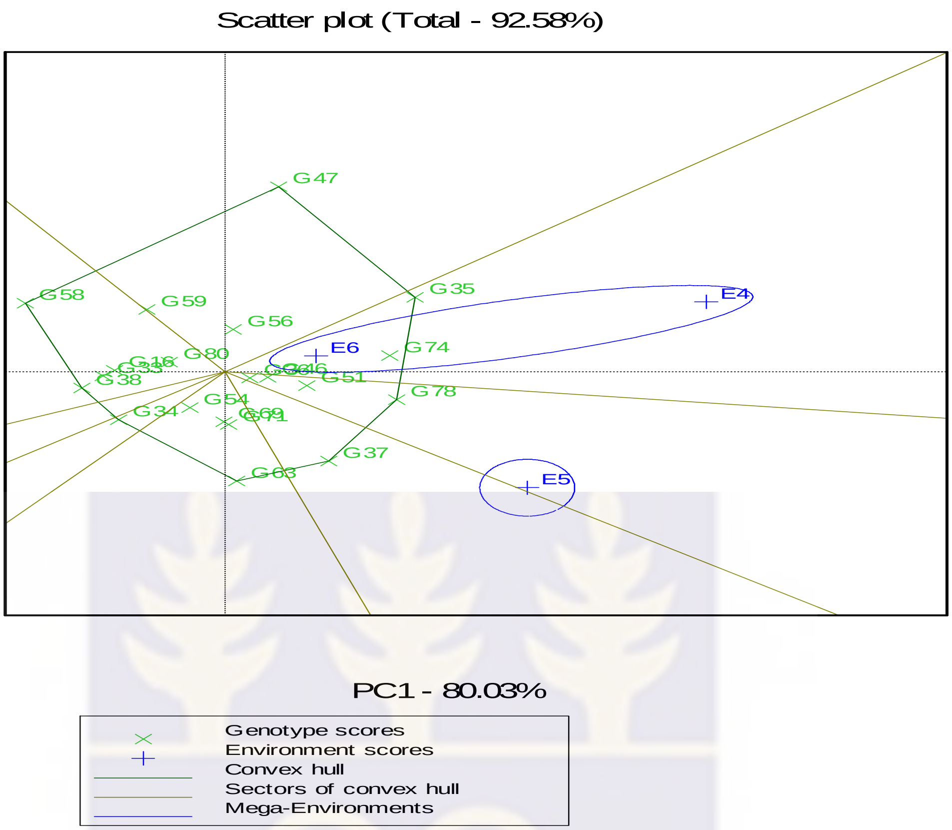

Figure 6-9 GGE biplots for fodder means per plant

E4 provided much information about the differences among genotypes in terms of fodder yield since its vector was considerably longer compared to that of other environments and it was along the biplots axis which accounted for 80.03 % of the trait variation. E4 also formed the smallest angle with PC1 and was therefore most representative of the mega-environment to which it belonged. E6 had shortest vector which means that the performance of all the genotypes was similar in that environment (Figure 6.10).

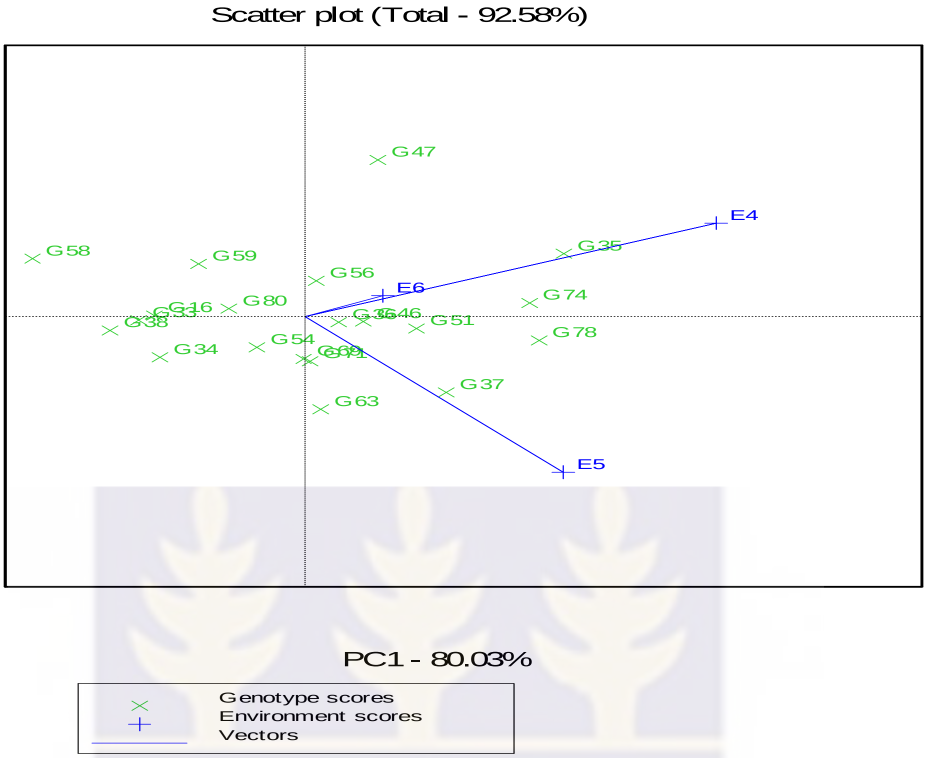

Figure 6-10 Discriminating power and representativeness of planting dates

6.3.8. Striga

Most of the genotypes were either resistant or tolerant to striga. The only cultivars that expressed susceptibility to striga were G34 and G16 (Table 6.18). G34 was however the most susceptible as in many plots, its plants died before reaching maturity. It had been the most susceptibe cultivar across the planting dates.

Table 6.18 Mean scores of genotypes for tolerance/susceptibility to striga across 2017 planting dates

Code	**Genotype**	**E4**	**E5**	E6	**Mean**
G47	Eldanke	0.52	1.48	0.83	0.94
G33	Dan batsatsa	1.08	0.52	1.33	0.98
G58	Dan bekori	0.83	1.08	1.13	1.01
G35	Dan dam	1.29	0.51	1.28	1.03
G51	Farin wake	0.84	1.08	1.29	1.07
G56	Dan mangaza	1.02	1.04	1.22	1.10
G63	Arnen wake	1.23	1.79	0.52	1.18
G74	Baadare	1.03	1.54	1.13	1.24
G38	Bagagi21	1.93	1.58	0.83	1.45
G78	Lakade	1.58	1.28	1.49	1.45
G71	Hwarin wake	1.78	1.28	1.29	1.45
G80	Dan baourota	1.13	2.13	1.29	1.52
G59	Darey	1.08	2.29	1.29	1.55
G54	Salga	1.05	2.08	1.84	1.66
G69	Gnagaou	2.04	1.79	2.23	2.02
G37	Tessa	2.23	1.93	2.11	2.09
G46	Bawada	2.28	2.73	1.52	2.18
G36	Tcheto	2.76	1.84	2.08	2.23
G16	Danila	4.04	2.02	2.01	2.69
G34	Bougou bougou	4.76	4.51	5.28	4.85
Mean		**1.73**	**1.73**	**1.60**	**1.68**

E4 = first planting. E5 = second planting date. E6 = last planting date.

Only one mega-environment was formed as there was no re-ranking of genotypes across the planting dates, in other words, the tolerant as well as the susceptible cultivars did not vary with environments (Fig. 6.11).

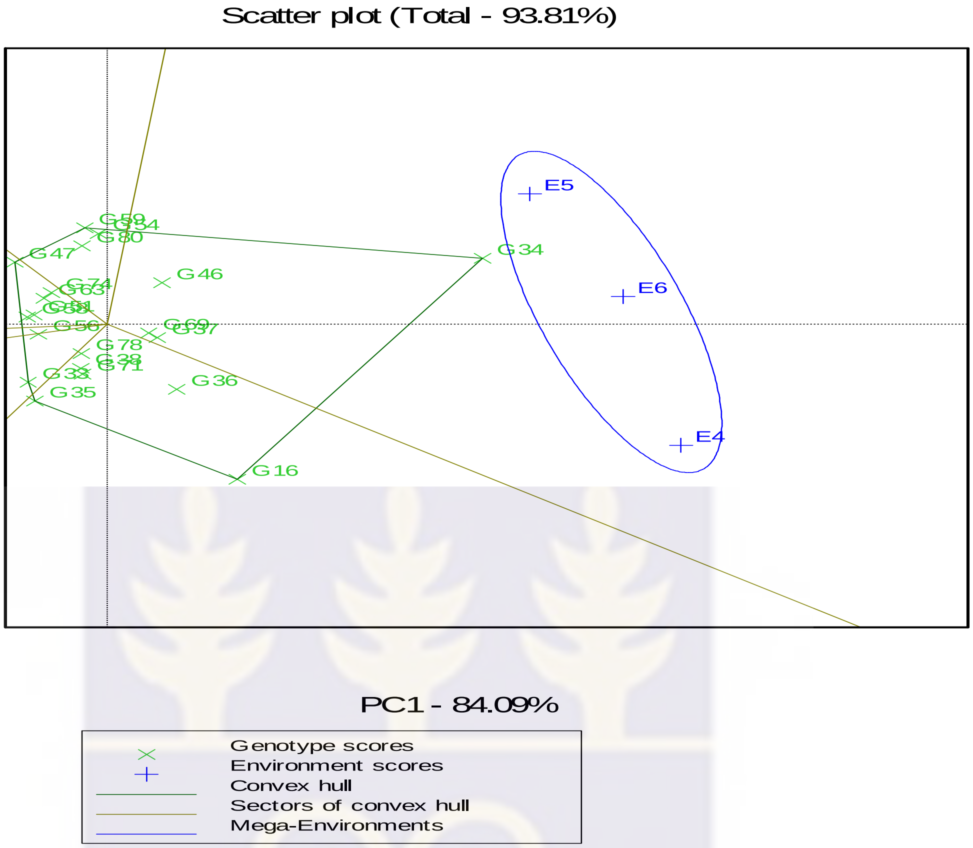

Figure 6-9 GGE biplots for striga infestation

6.4. Discussion

The significant genotype by planting date interaction detected for days to flowering, days to 50 % maturity, grain and fodder was an indication of planting date effect on these agronomic and yield parameters. This finding was consistent with Azari and Khajepour (2003) who asserted that planting date was part of the major factors affecting growth and yield of leguminous crops. It further agreed with Morakinyo and Ajibade (1998) who said that the quantity as well as the quality of cowpea seeds was influenced by rainfall amount and distribution which in turn was affected by planting time. Although, rainfall amount was greater in 2016 compared to 2017, significantly higher grain yield was recorded in the latter than the former. This may be because the soil of the 2016 experimental site was low in fertility, especially P in comparison to that of 2017, this support the claim of Payne (1997) who stated that low soil fertility causes yield reduction more than rainfall in the driest agro-ecology of the Sahel and other areas of West Africa.

The wide reduction in number of days to first flower appearance and days to 50 % maturity exhibited by all the genotypes in the last planting compared to first planting especially in 2016 was a signal of the cultivars sensitivity to photoperiod since the two periods were different in terms of daylength. Similar findings were reported by Akande *et al.* (2012) who noticed that cowpea varieties took long to reach 50 % maturity when planted in August compared to when they were planted in September. Similarly, a wide variation in days to 50 % flowering was exhibited by two late maturing improved varieties (IT99K-7-21-2-2 and IT99K-216-24-2) between July and August planting dates at Minjibir, an IITA station located in northern Guinea savanna of Nigeria (Sanda and Maina, 2013). Ehlers and Hall (1996) classified cowpea varieties as day neutral, quantitative short day and obligate short day based on their response to photoperiod and temperature. According to their classification, the lines tested in the present study exhibited a quantitative short day response as they expressed an increase in the number of days to appearance of flower buds under long days in comparison to short days. Furthermore, G34, G74, G78 and G47 seemed to be more sensitive to photoperiod as they started flowering towards the end of the season when the short days usually start in Niger. The sensitivity to photoperiod detected in these farmers’ cultivars was in agreement with Wien and Summerfield (1980) who while evaluating 24 cowpea accessions collected from farmers’ fields in Niger and Nigeria for adaptation to photoperiod, stated that flower initiation in local varieties of cowpea has been assigned to photoperiod control.

There were differential adaptation of genotypes to planting dates with regards to yield and yield components within and across the two years. Delay in planting resulted in significant reduction in grain yield. As a result, the planting dates of June 30 and July 7 (early plantings) recorded the highest grain yield, pod length and number of seeds per pod in 2016 and 2017. These findings were consistent with Mirzaienasab and Mojaddam (2014) and Dhital *et al.* (1997). It also corroborated with Ezeaku *et al*. (2015) who reported that early planting resulted in significantly higher yield and yield components compared to late sowing in derived savanna ecology of southeastern Nigeria. However, Akande *et al.* (2012) used four planting dates (June, July, August and September) and identified August sowing date as best adapted for grain yield in southern Guinea savanna of Nigeria. Also Mbong *et al.* (2010) stated that grains of early sowing were low in quantity and quality compared to those of late planting as a result of scab infection, hence in areas prone to scab disease late planting may be better than early planting.

The higher mean grain yield obtained from first planting dates in the present work was due to high performance of early maturing (less photosensitive) cultivars since late maturing highly photosensitive varieties (G34, G74, G78, G47 and G35) produced very low yield because the onset of its flowering occurred towards the end of the season regardless of planting date. In 2016 and 2017, the end of the rainy season was characterized by moisture as well as insect stresses and it negatively affected the yield of late maturing cultivars and late planted early maturing varieties. The combined effect of drought and *Clavigralla tomentosicollis* was the main reason why first sowing date (July) recorded considerably higher number of seeds per pod compared to last planting date (August). Innocent *et al.* (2013) found insignificant yield loss in early season planting while the loss was high and even total for late maturing varieties when planted late. The same authors noticed that population density of bruchids, maruca, pod sucking bugs and thrips was higher in late than early season. Similar findings were reported by Asante *et al.* (2001) who stated that the flowering and pod setting phases of late planted cultivars occurred at the time when the population of the three major post-flowering insects was at its peak leading to an economic yield loss. Ansobah *et al.* (2013) recommend early planting in Ghana to take advantage of more suitable weather conditions and less insects' damage. From the present results, high grain yield can be obtained in late planted cowpea when varieties used are tolerant to both terminal drought and pod sucking bugs, especially *Clavigralla tomentosicollis*. Sources of tolerance to drought (Fatokun *et al.*, 2012; Watanabe *et al.*, 1997) and to *Clavigralla tomentosicollis* (Koona *et al.*, 2002; Dabire-Binso *et al.*, 2010) had been reported, so development of varieties tolerant to both stresses is theoretically possible.

The present studies revealed that biological yield of cowpea was affected by planting time as very low fodder yield was recorded in the last planting date compared to the two first sowing. Mojaddam and Nouri (2014) detected significant planting date by genotype interaction; however they observed that fodder yield of July 23 sowing was 6.7 % greater than that of July 6. Sanda *et al.* (2013) also found wide fodder yield variation among improved cowpea varieties according to planting dates; they noticed that September sowing gave significantly lower yield in comparison to July and August planting dates.

6.5. Conclusion

Planting date had a significant effect on yield and yield related traits of local cowpea cultivars in Niger according to the results of the present work. Significant reduction in days to flowering and days to 50 % maturity with subsequent decrease in grain and fodder yield was observed when varieties were planted late. Therefore, planting should be done from the end of June to July 10th in order to obtain optimum yield of farmers cowpea varieties in Niger, however highly photosensitive cultivars should be avoided regardless of the planting date especially for grain production. No cultivar had been consistently the best across the planting dates; however G56, G59, G54, G33, G63 and G71 showed relatively good performance and further studies are needed to determine which of them to recommend for all or each sowing date.

CHAPTER SEVEN

7.0. General conclusions and recommendations

7.1. General conclusions

The most widely crops cultivated across the study areas were millet, cowpea, sorghum and groundnut. However millet and cowpea were the only ones well adapted to almost all the surveyed areas. Cowpea was mainly grown in association with millet. Farms were generally inherited as more than 82 % of respondents affirmed obtaining their farms from their parents. The mean farm size per household was 5.58 ha and varied from 3.23 to 7.24 across the study areas. The soil texture of farms was sandy according to the majority of respondents and most of the farms were located far from homes. About 60 % of respondents claimed that their farms were low in fertility, 75 % stated that their cowpea production was low. The results of both focus group discussion and household questionnaire revealed that drought and low soil fertility were the top constraints impeding cowpea production and yield. The major causes of soil fertility deterioration were collection of crop residues from farms and lack of fallow. Early maturity and high yielding potential were the farmers' preferences in terms of cowpea varieties. There was low level of formal education among farmers as more than 72 % of respondents have not been to school.

High genetic diversity was observed among genotypes with regard to adaptation to low soil P conditions. Lower means were recorded in dry season compared to rainy season for all the traits; however the difference was much larger in terms of plant height and shoot dry weight. There was differential adaptation of genotypes to the two seasons with respect to grain yield, but cultivars such as G118, G150, G149, G131 and G11 produced consistently high yield in both seasons.

G131 and G11 recorded even higher grain in dry compared to rainy season. Higher estimates of heritability, genetic variance, phenotypic variance as well as GCV and PCV were obtained in the rainy season. Grain yield was positively correlated with shoot dry weight, plant height and shoot color ; it was however negatively correlated with days to flowering and days to 50 % maturity. The highest positive correlation was detected between days to flowering and days to 50 % maturity.

Significant ($p < 0.01$. $p < 0.001$) genotype by environment interaction (G x E) was detected for all the parameters except grain yield, plant height, shoot dry weight, number of seeds per pod and pod length. The cumulative percentage of the PCA axis accounted for 93.66 and 84.51% of the total GEI variation in days to flowering and days to 50 % maturity respectively. However in the case of fodder yield, the whole GEI variation was due to the PCA components with the residual having zero contribution. The largest contribution of the genotypes to traits variation was observed in fodder yield (46.76 %) while the smallest was in shoot dry weight (1.5 %). Genotypes were also responsible for a significant variation with regard to days to flowering (21.57%) as well as grain yield (15.06 %). The environment was the main cause of the variability detected in shoot dry weight, plant height, days to 50 % maturity and grain yield with 82.45, 72.04, 58.69 and 36.55 % respectively. The GEI part of the variation was high in days to flowering (36.85 %), fodder yield (22.73 %) and days to 50 % maturity (18.66 %). The G x E interaction, although not significant for grain yield, contributed considerably (15.85 %) to the yield variation. The error had a great contribution in the variation observed in grain yield (32.54%). G118 and G98 were the best and worst performing cultivars with mean grain yield of 48.33 and 20.35 g per plant respectively. However none of them was stable according the AMMI stability value. G150 had a mean grain yield of 45.23 g per plant together with a stability value of 0.6, making it to be the most stable and high yielding cultivar. F_2 seeds were obtained from the crosses between G150, G118 (tolerant) on one hand and G5 (susceptible to P deficient soils) on the other. The cultivars means fodder yield across the environments varied from 31.24 to 121.42 g per plant. The superior genotypes were G197, G118 and G164 with respectively 121.42, 108.79 and 104.59 g per plant. However, all the high fodder yielding varieties showed differential adaptation to environments. The widely adopted improved varieties were highly instable and low in fodder yield.

The significant genotype by planting date interaction detected for days to flowering, days to 50 % maturity, grain and fodder was an indication of planting date effect on these agronomic and yield parameters. First planting dates recorded the highest mean grain yield in both 2016 and 2017 while the lowest belonged to last planting dates. Mean grain yield was 23.35, 15.94 and 12.67 g per plant for the first, second and third planting date in 2016 respectively. It was 58.15, 19.75 and 11.67 g per plant for planting date1, 2 and 3 in 2017. The best performing genotypes in 2016 were G63 and G33 while in 2017, the winning genotypes were G54, G59 and G56. G63, G33 and G71 produced highest grain yield for planting date1, 2 and 3 respectively in 2016. In 2017, G54 won in sowing date1 whereas G59 and G56 were the superior cultivars in date2 and 3 respectively.

7.2. Recommendations

Extension workers should encourage farmers to not only leave crop residues on the farm but also to apply manure to reduce soil fertility deterioration. Cowpea breeding program in Niger should take into account early maturity, high yielding potential, tolerance to drought and low soil P conditions. Varieties that tolerant to P deficient soils should also be tolerant to striga as the two stresses seemed to occur together on the field. Most of the high performing cultivars with regard to both grain and fodder were not stable, so specific recommendation will be made to environments. Genotypes with high grain and/or fodder yield in the dry season were detected, however further studies are necessary for selection of varieties for dry season cowpea growers. Farmers should plant cowpea from the end of June to the first decade of July in order to get optimum grain and former yield. However the use of highly photosensitive varieties should be avoided regardless of the planting dates except if they are tolerant to both terminal drought and pod sucking bugs especially *Clavigralla tomentosicollis*. No cultivar had been consistently the best across the planting dates; however G56, G59, G54, G33, G63 and G71 showed relatively good performance and further studies are needed to determine which of them to recommend for all or each sowing date.

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APPENDIX

Appendix 3.1. Focus group discussion interview guide

REPUBLIQUE DU NIGER
MINISTERE DE L'AGRICULTURE
Institut National de Recherche Agronomique du Niger (INRAN)

EVALUATION OF FARMERS' PERCEPTION OF SOIL FERTILITY IMPACT ON CROP PRODUCTION

FOCUS DISCUSSION INTERVIEW GUIDE

Region

Department

Commune

Village

1. List the crop grown in the area

2. Do you grow cowpea? Yes No
3. Type of varieties : Local______ Improved_____ Both ____
4. Do you treat the seeds before planting? Yes No
   If yes how do you it?

5. How do you grow cowpea? 1= Sole cropping 2= In association

Reasons :

Which crop was mixed with cowpea? ______________________________

6. Which cropping system is the best? Sole cropping____ Mixed cropping ____
7. Do you use fertilizers ? Yes No
8. Type of fertilizer used : ___________________
9. What are the cowpea production constraints in your area?
a. Drought
b. Insects
c. Diseases
d. Striga
e. Other witch weeds
f. Low soil fertility
g. Birds
h. Lack of quality seeds
i. Others
10. Rank five main production constraints based on yield loss caused

1__________________ 2 ________________ 3______________ 4_______________5______

11. How do you solve the problems?

12. Is low soil fertility a major constraint to cowpea production ?____Yes _____No
13. What factors contribute to soil fertility deterioration?

14. What impact does low soil fertility have on cowpea production?

15. How do you distinguish the symptoms of low soil fertility on cowpea?
16. How do you improve the soil fertility of your farms?
a. Fertilizer application
b. Organic manure
c. Compost
d. Fallow
e. Mixed cropping

f. Leaving crop residues on the field
g. None
h. Others

If you do not do any of the above, what are the reasons?

a. Lack of money
b. Not available in local markets
c. Transportation problem
d. High price
e. Lack of livestock
f. Low quality of inputs in local markets
g. Others

17. What impact does fertilizer application have on cowpea production?
1. Grain and fodder yield Improvement
2. Improve grain yield only
3. Improve fodder yield only
4. Others
5. General comments

Appendix 3.2. Household questionnaire

1. "Questionnaire Number"
2. "Enumerator code " 1 Abdou Souleymane" 2 "Issaka Hamani Boureima"
3. Region" 1 "Dosso" 2 "Maradi" 3 "Zinder"
4. Departement" 1 "Doutchi" 2 "Boboye" 3 "Loga" 4 "Dakoro" 5 "Mayahi" 6 "Guidan Roumdji" 7 "Tanout" 8 "Goure" 9 "Matameye"
5. Commune" .
6. Village"
7. Date"
8. Household head Name"
9. Age " Sex" 1 "M" 2 "F"
10. Marital status "1 "Maried" 2 "Single" 3 "Divorced" 4 "Widow"
11. Formal education level" 1 "None" 2 "Primary" 3 "Secondary" 4 "Tertiary"
12. Primary occupation" 1 "None" 2 "Student" 3 "Agriculture" 4 "Livestock rearing" 5 "Transportation" 6 "Small business" 7 "Retired worker 8 "Civil servant" 9 "Others"

;

13. Secondary occupation" 1 "None" 2 "Student" 3 "Agriculture" 4 " Livestock rearing " 5 "Transportation" 6 " Small business " 7 " Retired worker " 8 " Civil servant " 9 " Others "
14. Social status" 1 "Village chief" 2 "Opinion leader" 3 "Elected councilor" 6 " Just Farmer"
15. Member of farmer organization" Yes No

Data on farms: information was collected on a maximum of five farms for each respondent.

16. Farm1 "Code "

17. Name of the farm"

18. List of crop grown"

19. "Area in hectare"

20. "Cowpea production (grain) in last cropping season"

21. Type of variety used" 1 "Improved" 2 "Local" 3 "NA"

22. Do you leave crop residues on the farm" Yes No

23. How do you judge your cowpea production on that farm?" 1 "Low" 2 "Medium" 3 "Good" 9 "NA"

24. If you think the production is low, what could be the reasons?"

1 "Low rainfall" 2 "Uneven rain distribution" 3 "Flood" 4"Insects" 5 "Disease" 6 "Late planting" 7 "Late weeding" 8 "Inadequate management of the field" 9 "Soil not adapted to cowpea production" 10 "Eroded soil 11 "Low soil fertility" 12 "Low yielding variety" 13 "Poor quality seeds" 15 "Farm far from home" 16 "Others" 99 "NA"

25. Type of soil" 1 "Clay" 2 "Sand" 3 "Silt" 4 "Clay-sand" 5 "Clay-silt" 6 "Sand-silt" 7 "Others" 9 "NA"

26. Mode of acquisition" 1 "Inheritance" 2 "Purchase" 3 "Gift from government" 4 "Borrow" 5 "Hire" 6 "Others" 9 "NA"

;

27. Fertility level" 1 "Very fertile" 2 "Fertile" 3 "Poor" 4 "very poor" 9 "NA"

28. Farm soil erosion level" 1 "Soil not eroded" 2 "Eroded soil" 3 "very eroded soil " 9 "NA"

29. Have you applied mineral fertilizer to your farm?" 1 "Yes" 2 "No"

30. Have you applied organic fertilizer to your farm?" 1 "Yes" 2 "No"

31. Have you applied insecticide to your farm?" 1 "Yes" 2 "No"

32. Sex of the farm manager" 1 "Masculin" 2 "Féminin"

Varietal preference

33. Seed size" 1 "Large" 2 "Medium" 3 "Small"

34. Seed coat color" 1 "White" 2 "Dark Red" 3 "Red" 4 "Black" 5 " Speckled " 6 "Other"

35. Seed weight" 1 "Heavy" 2 "Medium" 3 "Light

36. Grain yield" 1 "High" 2 "Medium" 3 "Low"

37. Fodder yield" 1 "High" 2 "Medium" 3 "Low"

38. Drought tolerance" 1 "Early maturity" 2 "Tolerant" 3 "Susceptible"

39. Insects tolerance" 1 "Resistant" 2 "Tolerant 3 "Susceptible"

40. Resistance to Striga" 1 "Resistant" 2 "Tolerant" 3 "Susceptible"

41. Tolerance to low fertile soils" 1"Tolerant" 3 "Susceptible"

42. Maturity" 1 "Early" 2 "Medium" 3 "Late"

43. Dual purpose variety" 1 "Yes" 2 "No"

44. Taste" 1 "Good" 2 "Sweet" 3 "NA"

45. Cooking time" 1 "Long" 2 "Moyen" 3 "Short"

46. Market value" 1 "High" 2 "Medium" 3 "Low"

47. Choose the first five preferred traits and ranked it from 1 to 5

1 "Most preferred"   5 "Less preferred"

Appendix 4.1. List of cowpea genotypes used in the main season trial

ENTRY_No	VARIETY NAME	TYPE	ORIGIN
1	Gorom Local	Local	Burkina faso
2	IT98K-131-4	Improved	IITA
3	IT98K-205-8	Improved	IITA
4	IT04K-332-2	Improved	IITA
5	IT87D-1083	Improved	IITA
6	IT98K-630	Improved	IITA
7	IT91K186	Improved	IITA
8	Sadore local	Local	Niger
9	Oubritenga Beng Raogol1	Local	Burkina faso
10	LOCAL GOROUAL	Local	Niger
11	Local chical	Local	Niger
12	Halidou Djibo	Local	Niger
13	GEC	Local	USA
14	IT89KD-245	Improved	IITA
15	IT81D-994	Improved	IITA
16	Dan Illa INRAN	Improved	Niger
17	IT98D-1399	Improved	IITA
18	IT 90K-277-2	Improved	IITA
20	IT84S22-46-6	Improved	IITA
21	IT90K-76	Improved	IITA
22	Aloka	Local	IITA
23	Danila	Local	IITA
24	Dan Gorda	Local	Niger
25	Kwaama Shalla	Local	NIGER
26	IT07K-181-51	Improved	IITA
27	Hannoun Mareni Shalla	Local	NIGER
28	Mai Diya da Harawa lido	Local	NIGER
29	Dan Moukaddass Zanne	Local	NIGER
30	Dan Tchaana	Local	NIGER
31	Yawa	Wild	NIGER
32	Matarka Nawa Issufuri	Local	NIGER
33	Dan Batsatsa Kornaka	Local	NIGER
34	Bougou Bougou	Local	NIGER
35	Dan Dam Ali neino	Local	NIGER
36	Tcheto Dan kassari	Local	NIGER
37	Tessa Abdoulaye mai goshi	Local	NIGER
38	Bagagi 21 ans	Local	NIGER
39	Sababba Sata Gamram	Local	NIGER

40	Kafi Saley Kimba	Local	NIGER
41	Kwaama Maiki	Local	NIGER
42	Ouban Zaoura Dan saga	Local	NIGER
43	Farin wake Kantari	Local	NIGER
44	Lakade Karangiya Jimma	Local	NIGER
45	Gouma Sami Godje	Local	NIGER
46	Dan Bawada Daji	Local	NIGER
47	El Danke Maitsakoni	Local	NIGER
48	Dan Gawouna Gourgouzou	Local	NIGER
49	Dan Mallam Idi Dan saga	Local	NIGER
50	TAZAM	Local	ICRISAT
51	Farin wake Matankari	Local	NIGER
52	IT88D-867-11	Improved	IITA
53	IT97K-499-37	Improved	IITA
54	Salga Sabongari	Local	NIGER
55	Dan Baidari Nguiguimi	Local	NIGER
56	Dan Mangaza Wangarawa	Local	NIGER
57	Takatchame Jaja	Local	NIGER
58	Dan Bekori Bande	Local	NIGER
59	Darey kiota est	Local	NIGER
60	LOCALTAMOU	Local	NIGER
61	Baba Gamus Babul	Local	NIGER
62	Dan Baouchi Dan Saga	Local	NIGER
63	Arnen wake Matankari	Local	NIGER
64	Doungouri Bero Babiadey	Local	NIGER
65	SOUMBOUM BENG RAOGO 9	Local	Burkina faso
66	Nakoussou Jaja	Local	NIGER
67	Dan Tassaoua	Local	NIGER
68	TN 2780	Improved	NIGER
69	Gnagaou Lido	Local	NIGER
70	Dan Tonono Dan Saga	Local	NIGER
71	Hwarin wake kornaka	Local	NIGER
72	Dan Tahoua mayrere	Local	NIGER
73	MAMOUDA	Local	ICRISAT
74	Baadare Karanguiya	Local	NIGER
75	Dan galgagia Guidan Tagno	Local	NIGER
76	DAKIARA	Local	ICRISAT
77	Maitsakoni IT	Local	NIGER
78	Lakade Maiki	Local	NIGER
79	Dan Biri Faofao	Local	NIGER
80	Dan Baourota kornaka	Local	NIGER

81	Karadua Goure marche	Local	NIGER
82	Gnagaou Lido	Local	NIGER
83	Tanout marche	Local	NIGER
84	Yawa 04	Wild	NIGER
85	Juin 2015	Local	NIGER
86	Yawa20	Wild	NIGER
87	Kolozongo 01	Wild	NIGER
88	Tera 02	Wild	NIGER
89	Isv 368/it81D-994	Improved	NIGER
90	Tera	Wild	NIGER
91	Koukoki	Local	NIGER
92	Mallam Ibbo	Local	NIGER
93	Gada Dogo	Local	NIGER
94	Sabon Kafi sababba sata	Local	NIGER
95	Dan Biri Goure Marche	Local	NIGER
96	Dan Raha	Local	NIGER
97	KAOKIN LOCAL	Local	ICRISAT
98	NDIAMBOUR	Local	ICRISAT
99	SAKOURA LOCAL	Local	NIGER
101	Karadua Garam Tsofua	Local	NIGER
102	Sa babba sata Icrisat	Local	NIGER
103	Kelle kelle Mai Mundu	Local	NIGER
104	Dan Illa botsotso	Local	NIGER
105	Dan Sabo Jaja	Local	NIGER
106	Lakade karanguiya saidou souley	Local	NIGER
107	Dan Danko Karanguiya	Local	NIGER
108	Tamalalo Araouraye	Local	NIGER
109	Bagagi 12ans	Local	NIGER
110	MOUGNE	Local	NIGER
111	BF 18	Improved	ICRISAT
112	ECI185-158	Improved	ICRISAT
113	Maigondala Lido	Local	NIGER
114	ISV 128	Improved	ICRISAT
115	Bahaouche Mai Tsakoni	Local	NIGER
116	Yagaou Dan saga	Local	NIGER
117	Darey Doungouri	Local	NIGER
118	Botsotsuwa Ishirnawa	Local	NIGER
119	Dan Malam Boura Gueza	Local	NIGER
120	Lakade karanguiya	Local	NIGER
121	Lakade Kornaka	Local	NIGER
122	Koubakodey Salamatou	Local	NIGER

123	Dan Missira Halbawa	Local	NIGER
124	Dan Dam Mai 2015	Local	NIGER
125	Bonbohi Fabirdji	Local	NIGER
126	Garbey Doungouri Kalapate	Local	NIGER
127	Doungouri Bero Babiadey	Local	NIGER
128	KaraKAra Moussa Yagi	Local	NIGER
129	Ganda bery	Local	NIGER
130	Lakade Maiki	Local	NIGER
131	Dan Saley Kornaka	Local	NIGER
132	Sarkin Haoussa Tamalalo	Local	NIGER
133	Oloka Kantari Maigambo	Local	NIGER
134	Bata tatahi Rabi Ado	Local	NIGER
135	Lakade Dandaji Makaou	Local	NIGER
136	Lakade shalla	Local	NIGER
137	Kolalla Sa babba sata	Local	NIGER
138	Ajekoriya	Local	NIGER
139	Kollala Tanout	Local	NIGER
140	Kofadey Doungouri Yena	Local	NIGER
141	Kolalla Dan arbain	Local	NIGER
142	Dan Dam Guidan Tagno	Local	NIGER
143	Roumboukawa	Local	NIGER
144	Karadua Halbawa Tsaouni	Local	NIGER
145	Dan Kada Kouloumbouteye	Local	NIGER
146	Jan Pass Ismihou	Local	NIGER
147	Dan Watsatsa Kornaka	Local	NIGER
148	Oloka Maiki	Local	NIGER
149	Waken chaibou	Local	NIGER
150	Jiraini Ouban zaoura Jaja	Local	NIGER

Appendix 4.2. List of cowpea lines added in the minor season trial

ENTRY_No	VARIETY NAME	TYPE	ORIGIN
151	boutique Matankari	Local	NIGER
152	Massaw	Local	NIGER
153	NELOC-153	Local	NIGER
154	NELOC-154	Local	NIGER
155	NELOC-155	Local	NIGER
156	NELOC-156	Local	NIGER
157	NELOC-157	Local	NIGER
158	NELOC-158	Local	NIGER
159	NELOC-159	Local	NIGER
160	NELOC-160	Local	NIGER
161	NELOC-161	Local	NIGER
162	NELOC-162	Local	NIGER
163	NELOC-163	Local	NIGER
164	NELOC-164	Local	NIGER
165	NELOC-165	Local	NIGER
166	NELOC-166	Local	NIGER
167	NELOC-167	Local	NIGER
168	NELOC-168	Local	NIGER
169	NELOC-169	Local	NIGER
170	NELOC-170	Local	NIGER
172	NELOC-172	Local	NIGER
173	NELOC-173	Local	NIGER
174	NELOC-174	Local	NIGER
175	NELOC-175	Local	NIGER
176	NELOC-176	Local	NIGER
177	NELOC-177	Local	NIGER
178	NELOC-178	Local	NIGER
179	NELOC-179	Local	NIGER
180	NELOC-180	Local	NIGER
181	NELOC-181	Local	NIGER
182	NELOC-182	Local	NIGER
183	NELOC-183	Local	NIGER
184	NELOC-184	Local	NIGER
185	NELOC-185	Local	NIGER
186	NELOC-186	Local	NIGER
187	NELOC-187	Local	NIGER
188	NELOC- 188	Local	NIGER
189	NELOC-189	Local	NIGER

190	NELOC- 190	Local	NIGER
191	NELOC-191	Local	NIGER
192	NELOC-192	Local	NIGER
193	NELOC-193	Local	NIGER
194	NELOC-194	Local	NIGER
195	NELOC-195	Local	NIGER
196	NELOC-196	Local	NIGER
197	NELOC-197	Local	NIGER
198	NELOC-198	Local	NIGER
199	NELOC-199	Local	NIGER
200	NEWCO-41	Wild	NIGER
201	TN 256-87	Improved	NIGER
202	IT99K-573-1-5	Improved	IITA
203	TN3-78	Improved	NIGER
204	TN88-63	Improved	NIGER
205	IT90K-372-1-2	Improved	IITA
206	KVX30-309	Improved	BURKINA
207	Sa babba sata Icrisat1	Local	NIGER
208	IT97K-499-35	Improved	IITA
209	TN5-78	Improved	NIGER
210	Var 28 multi décor	Local	NIGER
211	Dan Biri goure	Local	NIGER
212	V15 Cowpea square	NA	NIGER
213	CS114	NA	NIGER
214	NEWCO-036	Wild	NIGER
215	Gnagaou Lido1	Local	NIGER
216	Doungouri Bero Babiadey1	Local	NIGER

Appendix 5.1. Combined ANOVA tables for traits

Days to flowering

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	3	2071.36	690.45	67.64	<.0001
Genotype	14	1584.54	113.18	11.09	<.0001
Rep(Env)	6	209.92	34.99	3.43	0.0039
Block(Rep)	6	18.10	3.02	0.30	0.9378
Env*Genotype	42	2947.15	70.17	6.87	<.0001
Error	105	1071.74	10.21		

Plant height

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	3	339469.09	113156.36	152.50	<.0001
Genotype	14	25655.39	1832.53	2.47	0.0048
Rep(Env)	6	44149.30	7358.22	9.92	<.0001
Block(Rep)	6	17128.27	2854.71	3.85	0.0017
Env*Genotype	42	41333.39	984.13	1.33	0.1269
Error	102	75687.30	742.03		

Shoot dry weight

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	3	106338.00	35446.00	249.38	<.0001
Genotype	14	1839.09	131.36	0.92	0.5359
Rep(Env)	6	4497.56	749.59	5.27	<.0001
Block(Rep)	6	1750.69	291.78	2.05	0.0655
Env*Genotype	42	6846.05	163.00	1.15	0.2861
Error	100	14213.72	142.14		

Days to 50 % maturity

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	3	4951.45	1650.48	109.74	<.0001
Genotype	14	795.39	56.81	3.78	<.0001
Rep(Env)	6	176.43	29.41	1.96	0.0795
Block(Rep)	9	154.85	17.21	1.14	0.3398
Env*Genotype	42	2051.94	48.86	3.25	<.0001
Error	98	1473.88	15.04		

Grain yield per plant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	3	17879.48	5959.83	24.36	<.0001
Genotype	14	10120.10	722.86	2.95	0.0009
Rep(Env)	6	4948.92	824.82	3.37	0.0047
Block(Rep)	9	3306.00	367.33	1.50	0.1590
Env*Genotype	42	12261.47	291.94	1.19	0.2390
Error	93	22754.85	244.68		

Fodder yield per plant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	12013.80	6006.90	10.40	<.0001
Genotype	15	99628.90	6641.93	11.50	<.0001
Rep(Env)	4	3893.35	973.34	1.68	0.1615
Block(Rep)	9	11354.69	1261.63	2.18	0.0315
Env*Genotype	30	57968.24	1932.27	3.35	<.0001
Error	81	46790.32	577.66		

Number of seeds per pod

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	1	2.76	2.76	1.21	0.2761
Genotype	14	40.00	2.86	1.26	0.2704
Rep(Env)	2	6.63	3.32	1.46	0.2433
Block(Rep)	9	31.75	3.53	1.55	0.1586
Env*Genotype	14	64.10	4.58	2.01	0.0376
Error	47	106.98	2.28		

Pod length

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	1	0.30	0.30	0.12	0.7352
Genotype	14	107.07	7.65	2.96	0.0027
Rep(Env)	2	6.87	3.44	1.33	0.2743
Block(Rep)	9	19.11	2.12	0.82	0.5992
Env*Genotype	14	42.83	3.06	1.18	0.3184
Error	47	121.44	2.58		

Pod yield per plant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	1	607.84	607.84	3.75	0.0587
Genotype	14	10591.48	756.53	4.67	<.0001
Rep(Env)	2	3283.20	1641.60	10.14	0.0002
Block(Rep)	9	1098.01	122.00	0.75	0.6588
Env*Genotype	14	6618.17	472.73	2.92	0.0030
Error	47	7610.84	161.93		

Harvest Index

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	1	0.04	0.04	1.51	0.2232
Genotype	20	1.72	0.09	3.64	<.0001
Rep(Env)	2	0.08	0.04	1.64	0.2011
Block(Rep)	6	0.08	0.01	0.57	0.7561
Env*Genotype	20	1.08	0.05	2.27	0.0059
Error	73	1.73	0.02		

Threshing percentage

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	1	40.82	40.82	0.58	0.4478
Genotype	20	2948.49	147.42	2.10	0.0119
Rep(Env)	2	181.57	90.78	1.30	0.2801
Block(Rep)	9	1475.73	163.97	2.34	0.0227
Env*Genotype	20	3279.94	164.00	2.34	0.0048
Error	70	4903.66	70.05		

Appendix 5.2. AMMI analysis of variance table for traits

Days to flowering

Source	df	SS	MS	F	F_prob
Total	179	8263	46.2	*	*
Treatments	59	6900	117.0	11.91	0.00000
Genotypes	14	1782	127.3	12.96	0.00000
Environments	3	2073	691.0	20.24	0.00000
Block	8	273	34.1	3.48	0.00129
Interactions	42	3045	72.5	7.39	0.00000
IPCA	16	2288	143.0	14.56	0.00000
IPCA	14	564	40.3	4.10	0.00001
Residuals	12	194	16.1	1.64	0.08936
Error	111	1090	9.8	*	*

Shoot dry weight per plant

Source	df	SS	MS	F	F_prob
Total	179	140961	787	*	*
Treatments	59	120065	2035	13.51	0.00000
Genotypes	14	2120	151	1.01	0.45344
Environments	3	111290	37097	60.18	0.00000
Block	8	4931	616	4.09	0.00028
Interactions	42	6655	158	1.05	0.40739
IPCA	16	4226	264	1.75	0.04757
IPCA	14	1735	124	0.82	0.64295
Residuals	12	694	58	0.38	0.96671
Error	106	15964	151	*	*

Plant height

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	179	580948	3246	*	*
Treatments	59	442029	7492	8.72	0.00000
Genotypes	14	29348	2096	2.44	0.00509
Environments	3	372401	124134	21.54	0.00000
Block	8	46104	5763	6.71	0.00000
Interactions	42	40281	959	1.12	0.32053
IPCA	16	19718	1232	1.43	0.13956
IPCA	14	15824	1130	1.32	0.21031
Residuals	12	4739	395	0.46	0.93388
Error	108	92816	859	*	*

Days to 50 % maturity

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	179	11205	62.6	*	*
Treatments	59	9365	158.7	10.43	0.00000
Genotypes	14	910	65.0	4.27	0.00001
Environments	3	6364	2121.4	80.01	0.00000
Block	8	212	26.5	1.74	0.09698
Interactions	42	2091	49.8	3.27	0.00000
IPCA	16	1387	86.7	5.70	0.00000
IPCA	14	380	27.2	1.78	0.05026
Residuals	12	324	27.0	1.77	0.06213
Error	107	1629	15.2	*	*

Grain yield per plant

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	179	80086	447	*	*
Treatments	59	47250	801	3.13	0.00000
Genotypes	14	12061	861	3.37	0.00018
Environments	3	22499	7500	8.86	0.00003
Block	8	6775	847	3.31	0.00208
Interactions	42	12690	302	1.18	0.24585
IPCA	16	6388	399	1.56	0.09288
IPCA	14	3384	242	0.95	0.51335
Residuals	12	2918	243	0.95	0.49957
Error	102	26061	255	*	*

Appendix 6.1: Combined analysis of variance table for traits across the planting dates of 2016 and 2017.

Grain yield

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	5	56513.96	11302.79	92.56	<.0001
Genotype	18	28318.29	1573.24	12.88	<.0001
Rep(Env)	5	926.07	185.21	1.52	0.1925
Block(Rep)	8	1037.79	129.72	1.06	0.3966
Env*Genotype	90	31683.23	352.04	2.88	<.0001
Error	90	10990.50	122.12		

Shoot dry weight

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	5	125839.69	25167.94	91.82	<.0001
Genotype	18	6765.77	375.88	1.37	0.1642
Rep(Env)	5	9018.04	1803.61	6.58	<.0001
Block(Rep)	8	5836.42	729.55	2.66	0.0111
Env*Genotype	90	24428.18	271.42	0.99	0.5179
Error	95	26038.48	274.09		

Plant height

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	5	89514.87	17902.97	16.97	<.0001
Genotype	18	60687.89	3371.55	3.20	0.0001
Rep(Env)	5	101192.30	20238.46	19.19	<.0001
Block(Rep)	8	21131.84	2641.48	2.50	0.0160
Env*Genotype	90	119765.41	1330.73	1.26	0.1293
Error	99	104415.40	1054.70		

Days to 50 % maturity

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	4	9543.32	2385.83	500.76	<.0001
Genotype	17	3477.89	204.58	42.94	<.0001
Rep(Env)	4	29.52	7.38	1.55	0.1971
Block(Rep)	4	51.05	12.76	2.68	0.0383
Env*Genotype	67	1660.77	24.79	5.20	<.0001
Error	73	347.80	4.76		

Appendix 6.2: Combined analysis of variance tables for traits across the planting dates of 2016

Days to flowering

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	2	5195.45	2597.73	205.86	<.0001
Genotype	19	3145.61	165.56	13.12	<.0001
Rep(Env)	2	36.02	18.01	1.43	0.2498
Block(Rep)	8	131.63	16.45	1.30	0.2638
Env*Genotype	38	806.65	21.23	1.68	0.0433
Error	49	618.32	12.62		

Days to 50 % maturity

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	2	9816.76	4908.38	1497.84	<.0001
Genotype	18	2308.99	128.28	39.15	<.0001
Rep(Env)	2	11.81	5.91	1.80	0.1764
Block(Rep)	8	31.89	3.99	1.22	0.3109
Env*Genotype	36	833.50	23.15	7.07	<.0001
Error	46	150.74	3.28		

Shoot dry weight

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	2	4183.01	2091.51	17.17	<.0001
Genotype	19	2261.06	119.00	0.98	0.5028
Rep(Env)	2	2057.69	1028.84	8.45	0.0008
Block(Rep)	8	1569.20	196.15	1.61	0.1493
Env*Genotype	38	2898.69	76.28	0.63	0.9281
Error	44	5358.17	121.78		

Plant height

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	2	12599.67126	6299.83563	4.93	0.0113
Genotype	19	52723.96819	2774.94569	2.17	0.0156
Rep(Env)	2	83396.83784	41698.41892	32.61	<.0001
Block(Rep)	8	26172.15822	3271.51978	2.56	0.0208
Env*Genotype	38	42227.22863	1111.24286	0.87	0.6705
Error	48	61383.0986	1278.8146		

Grain yield per plant

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Env	2	2697.34	1348.67	22.77	<.0001
Genotype	16	5603.42	350.21	5.91	<.0001
Rep(Env)	2	55.74	27.87	0.47	0.6293
Block(Rep)	8	446.13	55.77	0.94	0.4986
Env*Genotype	32	3550.17	110.94	1.87	0.0456
Error	29	1717.54	59.23		

Appendix 6.3. Combined analysis of variance table for traits across the planting dates of 2017

Plant height

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	33701.64	16850.82	14.42	<.0001
Genotype	19	49666.46	2614.02	2.24	0.0122
Rep(Env)	2	3634.78	1817.39	1.56	0.2214
Block(Rep)	8	12529.25	1566.16	1.34	0.2466
Env*Genotype	38	64498.06	1697.32	1.45	0.1088
Error	49	57261.07	1168.59		

Striga infestation

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	0.42	0.21	1.00	0.3755
Genotype	19	82.79	4.36	20.90	<.0001
Rep(Env)	2	0.52	0.26	1.24	0.2985
Block(Rep)	8	4.13	0.52	2.48	0.0242
Env*Genotype	38	14.18	0.37	1.79	0.0276
Error	49	10.22	0.21		

Grain yield

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	48417.46	24208.73	127.13	<.0001
Genotype	19	24405.91	1284.52	6.75	<.0001
Rep(Env)	2	1000.84	500.42	2.63	0.0828
Block(Rep)	8	1025.07	128.13	0.67	0.7126
Env*Genotype	38	19322.61	508.49	2.67	0.0008
Error	47	8950.26	190.43		

Shoot dry weight

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	12800.67	6400.33	15.30	<.0001
Genotype	18	10839.70	602.21	1.44	0.1588
Rep(Env)	2	3756.35	1878.17	4.49	0.0165
Block(Rep)	8	5746.85	718.36	1.72	0.1198
Env*Genotype	36	12144.17	337.34	0.81	0.7463
Error	46	19240.93	418.28		

Days to 50 % maturity

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	1	129.81	129.81	21.59	<.0001
Genotype	19	2431.94	128.00	21.29	<.0001
Rep(Env)	1	11.16	11.16	1.86	0.1836
Block(Rep)	8	104.86	13.11	2.18	0.0596
Env*Genotype	19	293.48	15.45	2.57	0.0108
Error	29	174.38	6.01		

Fodder yield per plant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	174944.23	87472.12	84.23	<.0001
Genotype	19	126103.54	6637.03	6.39	<.0001
Rep(Env)	2	14226.48	7113.24	6.85	0.0024
Block(Rep)	8	15252.86	1906.61	1.84	0.0927
Env*Genotype	38	73586.35	1936.48	1.86	0.0202
Error	49	50883.92	1038.45		

Seed number per pod

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	528.68	264.34	44.88	<.0001
Genotype	18	154.19	8.57	1.45	0.1675
Rep(Env)	2	40.15	20.07	3.41	0.0444
Block(Rep)	8	9.19	1.15	0.20	0.9898
Env*Genotype	36	129.19	3.59	0.61	0.9280
Error	35	206.14	5.89		

Pod length

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Env	2	130.30	65.15	17.96	<.0001
Genotype	18	169.65	9.42	2.60	0.0076
Rep(Env)	2	25.21	12.60	3.47	0.0420
Block(Rep)	8	23.12	2.89	0.80	0.6093
Env*Genotype	36	174.89	4.86	1.34	0.1947
Error	35	126.95	3.63		

Appendix 6.4 AMMI analysis of variance tables for traits across the planting dates of 2016 and 2017

Grain yield

Source	df	SS	MS	F	F_prob
Total	227	140911	621	*	*
Treatments	113	127729	1130	9.21	0.00000
Genotypes	18	33661	1870	15.24	0.00000
Environments	5	58890	11778	61.25	0.00000
Block	6	1154	192	1.57	0.16496
Interactions	90	35178	391	3.18	0.00000
IPCA	22	24832	1129	9.20	0.00000
IPCA	20	5460	273	2.22	0.00516
Residuals	48	4886	102	0.83	0.76171
Error	98	12028	123	*	*

Plant height

Source	df	SS	MS	F	F_prob
Total	227	541616	2386	*	*
Treatments	113	307616	2722	2.32	0.00001
Genotypes	18	71070	3948	3.37	0.00005
Environments	5	90295	18059	1.00	0.42199
Block	6	108453	18075	15.41	0.00000
Interactions	90	146251	1625	1.38	0.05307
IPCA	22	55558	2525	2.15	0.00515
IPCA	20	40565	2028	1.73	0.03942
Residuals	48	50129	1044	0.89	0.66916
Error	107	125547	1173	*	*

Shoot dry weight per plant

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	227	212127	934	*	*
Treatments	113	170443	1508	4.87	0.00000
Genotypes	18	8077	449	1.45	0.12469
Environments	5	136161	27232	16.66	0.00000
Block	6	9809	1635	5.28	0.00009
Interactions	90	26205	291	0.94	0.61529
IPCA	22	12320	560	1.81	0.02500
IPCA	20	6072	304	0.98	0.49087
Residuals	48	7813	163	0.53	0.99280
Error	103	31875	309	*	*

Fodder yield per plant

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	119	519361	4364	*	*
Treatments	59	430651	7299	6.29	0.00000
Genotypes	19	164648	8666	7.47	0.00000
Environments	2	174944	87472	11.63	0.00006
Block	3	22573	7524	6.48	0.00075
Interactions	38	91059	2396	2.07	0.00641
IPCA	20	52475	2624	2.26	0.00849
IPCA	18	38584	2144	1.85	0.04113
Residuals	0	0	*	*	*
Error	57	66137	1160	*	*

Appendix 6.5. AMMI analysis of variance tables for traits across the planting dates of 2016

Days to 50 % maturity

Source	df	SS	MS	F	F_prob
Total	113	13757	121.7	*	*
Treatments	56	13550	242.0	71.54	0.00000
Genotypes	18	2578	143.2	42.34	0.00000
Environments	2	10015	5007.7	604.10	0.00000
Block	3	25	8.3	2.45	0.07330
Interactions	36	957	26.6	7.86	0.00000
IPCA	19	751	39.5	11.69	0.00000
IPCA	17	206	12.1	3.58	0.00018
Residuals	0	0	*	*	*
Error	54	183	3.4	*	*

Grain yield

Source	df	SS	MS	F	F_prob
Total	101	18417	182.3	*	*
Treatments	50	16199	324.0	5.54	0.00000
Genotypes	16	7888	493.0	8.43	0.00000
Environments	2	3062	1530.9	85.27	0.00000
Block	3	54	18.0	0.31	0.82014
Interactions	32	5249	164.0	2.80	0.00144
IPCA	17	3776	222.1	3.80	0.00034
IPCA	15	1473	98.2	1.68	0.09937
Residuals	0	0	*	*	*
Error	37	2164	58.5	*	*

Days to flowering

Source	df	SS	MS	F	F_prob
Total	119	10462	87.9	*	*
Treatments	59	9664	163.8	12.45	0.00000
Genotypes	19	3576	188.2	14.31	0.00000
Environments	2	5195	2597.7	162.19	0.00000
Block	3	48	16.0	1.22	0.31174
Interactions	38	892	23.5	1.78	0.02340
IPCA	20	616	30.8	2.34	0.00637
IPCA	18	276	15.3	1.16	0.32017
Residuals	0	0	*	*	*
Error	57	750	13.2	*	*

Height

Source	df	SS	MS	F	F_prob
Total	119	333360	2801	*	*
Treatments	59	144794	2454	1.57	0.04563
Genotypes	19	69323	3649	2.33	0.00740
Environments	2	13702	6851	0.20	0.81649
Block	3	101010	33670	21.54	0.00000
Interactions	38	61769	1625	1.04	0.44064
IPCA	20	40165	2008	1.28	0.22789
IPCA	18	21604	1200	0.77	0.72676
Residuals	0	0	*	*	*
Error	56	87555	1563	*	*

Shoot dry weight

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	119	23110	194.2	*	*
Treatments	59	13010	220.5	1.66	0.03289
Genotypes	19	3486	183.5	1.38	0.17967
Environments	2	4753	2376.4	2.25	0.11587
Block	3	3173	1057.6	7.94	0.00019
Interactions	38	4771	125.5	0.94	0.57126
IPCA	20	3681	184.0	1.38	0.17447
IPCA	18	1090	60.5	0.45	0.96591
Residuals	0	0	*	*	*
Error	52	6927	133.2	*	*

Appendix6.6: AMMI analysis of variance tables for traits across the planting dates of 2017

Fodder yield per plant

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	143	246651	1725	*	*
Treatments	47	183403	3902	6.04	0.00000
Genotypes	15	115333	7689	11.90	0.00000
Environments	2	12014	6007	7.06	0.00142
Block	6	5103	851	1.32	0.25796
Interactions	30	56056	1869	2.89	0.00006
IPCA	16	38287	2393	3.70	0.00003
IPCA	14	17769	1269	1.96	0.02959
Residuals	0	0	*	*	*
Error	90	58145	646	*	*

Pod lenght

Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	113	769.2	6.81	*	*
Treatments	56	589.4	10.52	3.02	0.00013
Genotypes	18	248.6	13.81	3.96	0.00011
Environments	2	152.1	76.07	7.67	0.00141
Block	3	29.7	9.91	2.84	0.04895
Interactions	36	188.6	5.24	1.50	0.10091
IPCA	19	104.9	5.52	1.58	0.10581
IPCA	17	83.7	4.92	1.41	0.17891
Residuals	0	0.0	*	*	*
Error	43	150.1	3.49	*	*

Number of seeds per pod

Source	df	SS	MS	F	F_prob
Total	113	1247.8	11.04	*	*
Treatments	56	975.1	17.41	3.48	0.00002
Genotypes	18	225.4	12.52	2.50	0.00704
Environments	2	585.8	292.89	15.33	0.00001
Block	3	57.3	19.11	3.82	0.01644
Interactions	36	163.9	4.55	0.91	0.61292
IPCA	19	84.4	4.44	0.89	0.59948
IPCA	17	79.5	4.67	0.93	0.54332
Residuals	0	0.0	*	*	*
Error	43	215.3	5.01	*	*