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*Review*

## **Benefits of grass-legume inter-cropping in livestock systems**

**Unathi Gulwa<sup>1\*</sup>, Nobulungisa Mgujulwa<sup>1</sup> and Solomon T. Beyene<sup>2</sup>**

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**Legumes (*Fabaceae*) are plants with the distinct ability to fix atmospheric nitrogen, the atmospheric nitrogen fixation by legumes is known as biological nitrogen fixation. Biological nitrogen fixation is the process whereby atmospheric nitrogen is reduced to ammonia in the presence of the enzyme nitrogenase. Nitrogen fixation in legumes starts with the formation of nodules. Inside the nodules, nitrogen fixation done by the bacteria (*Rhizobia*), and the ammonia (NH<sub>3</sub>) produced is absorbed by plant. The symbiotic relationship between a bacterium and a plant makes legumes special plants, which offer benefits when included in farming systems. These benefits are ecosystem, economic and environmental benefits. Inclusion of forage legumes in the form of intercropping in low-input grassland mixtures improves forage quantity, quality and soil fertility through addition of nitrogen (N) from N<sub>2</sub>-fixation. Intercropping is a multiple cropping practice, which involves growing two or more crops in proximity. Legumes also improve the nutritive value of the low quality native pastures grown with them and are important component of farming system since they have high nutritive value and able to rehabilitate nutrient depleted soil. There are various factors affecting legume growth and development and these factors need to be taken into account when planning to grow legumes. These factors include pedoclimatic factors especially those associated with the soil acid complex. These factors are known as physical, chemical, biological and environmental factors. The improvement of forage quantity and quality through forage legume inclusion is crucial for improved animal performance, which is a goal of all livestock farmers. The inclusion of forage legumes in low-input grassland mixtures is vital to improve biomass production, forage quality and ultimately soil fertility. The improvement of forage quantity and quality is crucial for improved animal performance, which is a goal of every livestock farmer. Forage legumes have the potential to improve the diets of ruminants because they increase the crude protein (CP) concentration of the herbage mixture relative to that of grass monocultures.**

**Key words:** Legumes, biological nitrogen fixation, forage quality, forage quantity.

### **INTRODUCTION**

Legumes (*Fabaceae*) are plants with the special ability to fix atmospheric nitrogen, the process of atmospheric nitrogen fixation by legumes is known as biological nitrogen fixation. Legumes can supply up to 90% of their

own nitrogen (N) when inoculated with a proper strain of *Rhizobia*. Even though legumes fix nitrogen from the atmosphere they can also take up large quantities of soil nitrogen if it is available (Weisany et al., 2013). Biological

nitrogen fixation is a natural process that is of significant importance in the world of agriculture (Herridge et al., 2008). Biological nitrogen fixation is the process whereby atmospheric nitrogen is reduced to ammonia in the presence of nitrogenase (Herridge et al., 2008).

Nitrogenase is an enzyme found naturally only in microorganisms such as symbiotic *Rhizobium*, *Frankia*, or the free-living *Azospirillum* and *Azotobacter*. In this case, the focus is on nitrogen fixation by legume plants in association with *Rhizobia*. In symbiotic relations, microorganism infects the plant root through the infection thread and lives in the nodule forming structure. The plant supplies component of nitrogenase and organic compounds to microorganisms while the microorganisms supply reduced nitrogen to the plant. The symbiotic relationship between the bacteria and the legume plant allows them to both grow and produce a high protein seed or forage crop (Coskan and Dogan, 2011). Although, biological nitrogen fixation is dependent on host cultivar and *rhizobia* it is also limited by pedoclimatic factors especially those associated with the soil acid complex of high aluminium (Al) and manganese (Mn), low calcium (Ca) and phosphorus (P). These factors are categorized as physical, chemical, biological and environmental factors (Bordeleau and Prevost, 1994).

Legume production in relation to biological nitrogen fixation also offers a number of benefits and these benefits are characterized as ecosystem, economic and environmental benefits. Inclusion of forage legumes in the form of intercropping in low-input grassland mixtures improves biomass production, forage quality and soil fertility through addition of nitrogen (N) from N<sub>2</sub>-fixation. Intercropping is a multiple cropping practice, which involves growing two or more crops in proximity. Legumes also improve the nutritive value of the low quality native pastures grown with them and are important component of farming system since they have high nutritive value and able to rehabilitate nutrient depleted soil. Diverse mixtures of plant species can use resources more efficiently in nutrient-poor environments (Hector, 1998), and can produce more biomass than communities of one or few species (Cardinale et al., 2007; Hector et al., 1999). For example, if plants differ in depth of rooting they can exploit nutrients from different soil layers (Wilson, 1988). Mixtures can use the sunlight more efficiently than monocultures through improved interception of light (Spehn et al., 2005). Furthermore, components of a mixture may show nutritional complementarity. Effects of legumes can persist even if the proportion of legumes in the total biomass is small (Mulder et al., 2002; Nyfeler et al., 2011).

Positive interactions were observed among non-legume species (van Ruijven and Berendse, 2003; Hooper and Dukes, 2004). In agricultural ecosystems, grass–legume mixtures have the potential to increase productivity, herbage nutritive value and resource efficiency (Peyraud et al., 2009). Results of a pan-European experiment, using two grasses and two forage legumes at thirty-one sites for three years, showed strong positive mixing effects. This improved livestock production considerably in addition to benefits in soil fertility (Nandi and Haque, 1986). Grass species can benefit from growing in mixtures with legume species (Temperton et al., 2007), and N fixation of legume species can be enhanced with competition from non-legume species (Nyfeler et al., 2011). Losses from weed competition represent a significant waste of resources (that is, water and nutrients) in agricultural systems, and more efficient use of resources in diverse grass–legume mixtures makes them more resistant to the invasion of weeds than communities composed of fewer species (Frankow-Lindberg et al., 2009). Greater evenness of species in a mixture further increases their resistance to weed invasion (Tracy and Sanderson, 2004).

Niche complementary and resistance to weeds and diseases can result in greater yield in mixtures than would be expected from the component species growing separately (Trenbath, 1974). Meta-analysis carried out by Cardinale et al. (2007) showed that mixtures were more productive than the average monoculture in 79% of the forty-four experiments they summarized. The most diverse mixture used in the experiments achieved 17 times the biomass of the average of the monocultures and 88 times the yield of the most productive species grown in monoculture. In 12% of the experiments, the mixtures were more productive than the most productive monoculture. While it is desirable in agronomic systems to achieve good yields, it is no less important to obtain herbage of high digestibility; low fibre content and high concentration of protein, to sustain satisfactory animal production (McDonald et al., 2002).

Forage legumes generally have higher nutritive value than grass species. Growing grasses and legumes in mixtures can improve herbage nutritive value compared with grass monocultures (Zemenchik et al., 2002). The improvement in nutritive value is due to slower decline in digestibility with advancing maturity and higher levels of protein in legumes (Dewhurst et al., 2009). Therefore, this review explores the benefits of grass-legume mixtures in forage production and ultimately livestock productivity, factors affecting legume production, benefits of legume inclusion on the soil and plants grown in

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association with legumes.

## LITERATURE REVIEW

### Benefits of growing legumes

There are various benefits to the ecosystem function associated with growing legumes. These benefits are connected to the legumes' biological nitrogen fixation ability. They are categorized as economic, environmental and ecosystem benefits. Biological nitrogen fixation by legumes also presents benefits to the non-legume plants grown in association with legumes and the soils on which they are grown (Giller, 2001).

### Environmental benefits

The use of N fertiliser contributes substantially to environmental pollution therefore; biological alternatives have received increasing attention in the recent past in agricultural practices. Biological nitrogen fixation can act as a sustainable source of N and can complement or replace fertiliser inputs. Intercropping legumes capable of symbiotic N fixation offers an economically attractive and ecologically efficient means of reducing N inputs (Paynel et al., 2007). The assimilation of all the biologically fixed nitrogen by a legume plant, which maintains the balance of global nitrogen cycle and keeps nitrogen in a form that does not pollute the environment, is one of the well-known benefits of biological nitrogen fixation. Legumes contribute to enhanced carbon (C) sequestration and reduced greenhouse gas (GHG) emissions. The enhancement of C sequestration in the soil is related to increased biomass and hence to soil fertility. Raising soil fertility is viewed as the most effective way to rapidly increase C sink capacity (Serraj, 2004). Legumes also reduce GHG emissions from ruminant systems. The reduction of methane production has been seen in trials that were done on *Lotus corniculatus* (birdsfoot trefoil), *Lotus uliginosus* (greater trefoil) which are legumes possessing secondary metabolites known as condensed tannins (CTs) in their leaves. When household sheep were fed with these legumes, their methane production values decreased in comparison to those of the sheep that were on ryegrass pastures. The role of legumes in supplying N through fixation is crucial and beneficial in relation to GHG balance than had once been thought (Abberton, 2010).

### Ecosystem benefits

The amount of nitrogen contributed to the biosphere through biological nitrogen fixation is estimated to range between  $63 \times 10^6$  and  $175 \times 10^6$  tonnes per year. Symbiotic nitrogen fixation in legumes contributes about

30% to this amount of fixed nitrogen. Leguminous nitrogen fixation is viewed as the most efficient system as the mean yearly fixation rate ranges between 55-140 kg/ha in comparison with 0.3-30kg/ha for other nitrogen-fixing biological systems. In a study that was conducted in the United Kingdom, it was estimated that *Trifolium repens* (white clover) in mixture with grasses fixed up to 280 kg/ha annually. This introduction of white clover into the sward resulted to saving up to 45% nitrogen fertilizer (Lindstrom, 2001). The role of legumes in supplying N through fixation is crucial and beneficial in relation to GHG balance than had once been thought (Abberton, 2010). Powers et al. (2011) reported increases in soil carbon stock when forest or savanna was converted to pastures (5 to 12% and 10 to 22%, respectively).

### Economic benefits

Since adequate animal nutrition is essential for high rates of gain ample milk production, efficient reproduction and adequate profits, it is imperative to provide livestock with protein supplements when forage quality is low. The protein supplements are expensive and this results in high feed costs that compel dairy farmers to become more efficient with their farm operations. Feed accounts for approximately one-half of the total cost of providing milk, and high quality forage optimizes the productivity of the animals, therefore increasing the quality of forage available is one of the best methods of improving overall feeding efficiency. Combining the growth of cereal or grass forage with crops which are capable of increasing the protein content of the overall ration clearly has nutritional and financial benefits. Legumes are a good source of protein and can be used to compensate cereal or grass protein shortage (Eskandari et al., 2009). Thus, growing of plant mixtures with legumes, which is referred to as intercropping, can boost the forage protein content of ruminant diets. Several authors have reported higher crude protein content in grass-legume mixtures in comparison to sole cereals or grasses (Eskandari et al., 2009; Ojo et al., 2013).

### Benefits to the soil

Benefits to the soil emanating from biological nitrogen fixation by legumes include the improvement of soil organic matter content, soil porosity, soil nutrients, soil structure, soil pH, biological diversity and pest cycle (Heenan et al., 2004; Malik, 2010; Mohammadi et al., 2012; Ernst and Siri-Prieto, 2009).

### Soil organic matter

Soil organic matter is the organic fraction of the soil and



is composed of the decomposed plant and animal material, and microbial organisms. The carbon associated with the soil organic matter (SOM) is known as soil organic carbon. SOM is a key indicator of soil quality as it influences biological activity, serves as a nutrient reservoir, and impacts soil aggregation. Seeding of grasses with legumes in combination with continuous grazing resulted in increased SOC of pastures even though that did not translate into improved net returns (Heenan et al., 2004). From a long-term rotational study in Wagga Wagga in the United States of America, it was reported that stubble retention in legume-wheat rotation maintained higher levels of soil organic carbon (SOC) than stubble burning (Heenan et al., 2004). Rotations involving medics and vetch (*Vicia faba*) led to a significant increase in soil organic matter ranging between 12.5 to 13.8g/kg versus 10.9 to 11 g/kg for continuous wheat and wheat/fallow (Malik, 2010). Most crop residues contain more carbon than nitrogen but require both N and C to speed up the process of decomposition therefore the nitrogen contained by legumes facilitates the decomposition of crop residues in the soil and their conversion to soil building organic matter (Mohammadi et al., 2012). Several researchers have reported that crop mixtures greatly increased carbon inputs into the soil in comparison to monocultures. The increase in soil organic carbon was reported to be due to plant mixtures providing good soil cover, which ultimately results to continuous addition of roots and plant litter (Ernst and Siri-Prieto, 2009; Peypers et al., 2010; Tesfaye et al., 2007; Huntjes and Albers, 1978; Anders et al., 1996).

### Soil porosity

Most legumes have an aggressive taproot that opens pathways deep into the soil. Nitrogen rich legumes also encourage earthworms and burrows formation. The root channels and earthworm increase soil porosity and promote air movement and water percolation deep into the soil. Planting of white clover resulted in improvements in water percolation rate and the extraction of nutrients by plants from the soil. Transient structuring of soil and greater drainage of water through soil cores than under perennial ryegrass monocultures around the roots of white clover has also been reported (Graham and Vance, 2000).

### Nutrient recycling

Biennial and perennial legumes usually root deeply into the soil, and therefore they have the ability to recycle crop nutrients that are deep in the soil profile. This prevents nutrient loss due to leaching below the root

zone of shallower-rooted crops in rotation (Mohammadi et al., 2012).

### Improvement of soil structure

Legumes improve soil structure and stability. The protein, glomalin that symbiotically occurs along the roots of legumes serves as glue that binds soil together into stable aggregates. The aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting (Mohammadi et al., 2012). Improved soil structure reduces the risk of soil compaction and water runoff and ultimately increases the soil's biological activity, seedling establishment and root penetration. Legume driven soil structure improvement may result in increased leaching of both fixed and applied nitrate in legume monocultures (Holtham et al., 2007).

### Improvement of soil pH

Due to the legumes' acquisition of nitrogen as diatomic N rather than as nitrate, they lower the pH of the soil. This in turn promotes increased plant-soil-microbial activity in soils with a pH above the range for optimum crop growth and development (Graham and Vance, 2000).

### Biological diversity

Biodiversity is a major co-benefit of an increased use of legumes. This has been proved in long-term studies conducted in Minnesota where, the net soil accumulation of C and N of 1 m was measured on agriculturally degraded soils. Five hundred to six hundred percent C and N diversity increase were observed in perennial grasslands than monocultures. In these mixtures, there was also greater root biomass accumulation especially from legumes and C4 grasses. White clover and birdsfoot trefoil biomass presence were observed to significantly increase the pools of C and N in the soil (Abberton, 2010).

### Break pest cycle

Legumes can provide an excellent break in a crop rotation that reduces the build-up of grassy weed problems, insects and diseases. Forages and legumes also play an important role in weed control and nitrogen (N) supply for an upcoming crop. According to Malik (2010), the introduction of grain legume crops or legume-rich pastures provided N to subsequent cereal or oilseed crops when legumes were introduced into rotations. Besides, breaking pest cycles, grain legume crops also

lower infestation of non-legume crops by improving biological pest control through increased microbial diversity and activity (Lupwayi et al., 2011). Cereals rotations with legumes were useful because the legumes contributed N to the soil/ plant system and interrupted pathogen cycles. In Ethiopia, a faba bean (*Vicia faba L.*)-Wheat-wheat rotation reduced the severity of wheat take-all (*Gaeumannomyces herpotrichoides*) disease in comparison with wheat monoculture (Lupwayi et al., 2011).

## Benefits to the plant

### Improved biomass production

Legumes supply nitrogen to grass-legume mixtures, so mixtures may produce more forage yield than grasses grown alone. Generally, in grass-legume mixtures higher yields have always been achieved in comparison with sole grass plots. Several authors have reported, greater total dry matter production in grass-legume mixtures higher yields in comparison with sole grasses or cereals. In a study that was conducted by Sturludottir et al. (2013), in Northern Europe and Canada higher yield in the legume-grass mixtures than monoculture treatments were reported. The authors reported that on average, the grass-legume mixture plots had 9, 15 and 7% more DM than the most productive monoculture in the first, second and third year respectively. Sturludottir et al. (2013) reported more DM production of 9, 15 and 7% in mixture plots than the most productive monoculture in the first, second and third year respectively in a study they conducted. Gulwa et al. (2017) also reported higher total dry matter production in grass-legume mixture plots in comparison to grass only plots in a study that was conducted in the Eastern Cape Province, South Africa. The difference in growth patterns of legumes is reported to have a potential of leading to efficient use of resources such as light when grown in a mixture than when grown separately. All these different functional traits could contribute to positive interactions between the species resulting in higher yields for mixtures in comparison to monocultures. The attainment of high DM yield in the grass-legume mixture plots may also be attributed to beneficial effects of mixing grasses and legumes and also from the differences in the seasonal growth pattern between the grass and legume species (L€ uscher et al., 2005) or across years (Nyfeler et al., 2009).

### Improved nutritive value

Grasses grown in association with legumes also contain a higher percentage of protein. The protein content of legumes is typically much higher than that of grasses and

legumes fibre tends to digest faster than grass fibre, allowing the ruminant to eat more of the legume. Well nodulated legumes mostly provide an actual N supply to the subsequent crop but the net addition of this N and its availability depends on the amount of fixed N, which remains in non-harvested residues (Russelle, 2004). Grass in pure stands is common (that is, grass in natural systems), but requires high nitrogen (N) inputs. In terms of N input, two-species (grass-legume mixtures) are more sustainable than grass in pure stands and consequently dominate low N input grasslands (Nyfeler et al., 2011; Nyfeler et al., 2009; Crews and Peoples, 2004). In temperate grasslands, N is often the limiting factor for productivity (Whitehead, 1995). Plant available soil N is generally concentrated in the upper soil layers, but may leach to deeper layers, especially in grasslands that include legumes (Scherer-Lorenzen et al., 2003) and under conditions with surplus precipitation (Thorup-Kristensen, 2006). Eskandari et al. (2009) reported that grasses grown in intercropping with legumes contained a higher CP content than grasses harvested from the monoculture planted plots. This suggests that legumes grown alongside non-legume plants increase the N uptake of the companion plants by partitioning the atmospheric fixed N by legumes to the non –nitrogen fixing plants grown in association with them. Ojo et al. (2013) reported higher CP levels on *Panicum maximum* intercropped with *Lablab purpureus* in a study they conducted at the Federal University of Agriculture in Nigeria. Concentrations of nutrients in forage plants are dependent upon the interaction of a number of factors. These factors include the following: the physiology of the plant, physical and chemical compounds of the plant (tannins, cellulose and crude fibre), season and soil quality in which the forages are grown.

## Factors affecting legume development and production:

Factors affecting legume production include soil related factors such as soil pH, organic carbon, and mineral contents and plant factors such as plant nutrient status (Coskan and Dogan, 2011; Weinsany et al., 2013; Serraj and Adu-Gyamfi, 2004; Sinclair and Vadez, 2002).

### Soil related factors

#### Soil pH

Soil reaction (pH) is one of the most crucial factors influencing legume and *rhizobium* symbiosis. Higher hydrogen cation (H<sup>+</sup>) concentration ions lead to increased solubility of Aluminium (Al), Manganese (Mn) and Iron (Fe) and the high amount of these elements may

become toxic to the *rhizobium*. *Rhizobium* such as *Sinorhizobium meliloti* and *Rhizobium galegae* are highly sensitive to acid pH as soil pH less than 4.6 inhibits their activity. Some of the studies conducted in the past have shown formation of efficient symbiosis and increased amounts of biological nitrogen fixation when the soil pH is between 5.6 and 6.1. Soil acidification impedes the root hair infection process and nodulation (Coskan and Dogan, 2011).

## Soil macronutrient

### Nitrogen

Even though legumes can fix nitrogen from the atmosphere, they can take up large quantities of soil nitrogen if it is available. Nitrogen is an important element for the formation of soil organic matter. Nitrogen (N) release from a legume crop occurs as the aboveground plant residues, roots and nodules gradually decompose. Although there are contrasting reports of the role of starter N on BNF, it is widely agreed that, excess N inhibits nodulation and N<sub>2</sub> fixation, especially in soils with good fertility status (Serraj and Adu-Gyamfi, 2004; Unkovich et al., 2008). The negative effect of nitrate on legume nodulation and subsequent reduction in BNF is attributed to the inhibition of root infection, nodule development and nitrogenase activity (Weinsany et al., 2013).

### Phosphorus

Nodule development and function are critical sinks for phosphorous (P) therefore; nodules usually require the highest P content in the plant (Sinclair and Vadez, 2002). Adequate P fertilization has been observed to yield to enhanced nodule number, mass and greater N<sub>2</sub>-fixation activity per plant (Serraj and Adu-Gyamfi, 2004). Legumes release fixed N and build up soil organic matter during growth. The increase in soil organic carbon was reported to reach a new plateau after only three years on a clay soil on a study that was done on alfalfa (Sinclair and Vadez, 2002). The deficiency of phosphorus (P) supply and the availability poses a severe limitation on nitrogen fixation and symbiotic interactions. However, there are differences in phosphorus requirements of various *rhizobia*. The slow growing *rhizobia* are more tolerant to low P levels than the fast growing *rhizobia* (Russelle, 2004).

### Potassium

Although potassium (K) is not viewed as an integral

constituent of the metabolite, it serves to activate various enzymes, serves as a counter ion and is the major cationic cellular osmoticum. Potassium affects the growth rate of internodes. For some *rhizobia*, a qualitative requirement for K was seen when *Rhizobium Trifolii* and *Rhizobium Meliloti* revealed restricted growth when potassium was omitted from a defined medium whereas a linear response was obtained in batch culture (Russelle, 2004).

## Sulphur

Sulphur (S) is an essential element for growth and physiological functioning of the plants. The sulphur containing amino acid cysteine and methionine play an important role in the structure conformation and function of proteins and enzymes in vegetative plant tissue. As synthetic media for growth of *rhizobia* contains S, there has been very little attempt made to define quantitative requirements of sulphur. When examining S nutrition of two strains of *Bradyrhizobium japonicum* and two strains of *Bradyrhizobium sp.* using batch and chemostat cultures, high levels of contaminating S present in the media components had to be removed before S limitation occurred in the batch culture. The growth of four *Bradyrhizobia* strains was limited in the chemostat culture when the S concentration in the inflowing media was less (Unkovich et al., 2008; Weisany et al., 2013).

## Soil essential micronutrient content related factors

### Boron

Boron (B) is amongst the eight essential micronutrients that are also known as trace elements required for the normal growth of most plants. Strong alterations in nitrogen fixation in soybean plants were reported when B supply was low. Results of a study that was done on the effect of B on the *rhizobium*- legume cell surface interaction and nodule development in peas indicated that the number of *rhizobia* infecting the host cells and the number of infection threads (the infection threads developed morphological abnormalities) were reduced in boron deficient plants. The cell walls of boron deficient plants with structural aberrations lack the covalently bound proline rich proteins contributing to O<sub>2</sub> barrier, preventing inactivation of nitrogenase associated with a decline in N<sub>2</sub> fixation (Sinclair and Vadez, 2002).

### Copper

Copper (Cu) plays an important role in a protein expressed co-ordinately with nifgenes and may affect the

efficacy of bacteroid function. This element also plays an important role in the respiratory proteins that are required for the  $N_2$  fixation in *rhizobia*. Several *rhizobial* strains, particularly *R.leguminosarum* bv phaseoli make the pigment melanin. Cu deficiency in subterranean clover reduces nitrogen fixation (Abberton, 2010; Weisany et al., 2013).

### **Iron**

Iron (Fe) is required for various key enzymes of the nitrogenase complex as well as for the electron carrier ferredoxin and some hydrogenases. A particular high iron requirement exists in legumes for the heme component of haemoglobin. Iron is required in higher amount for nodule formation in legumes than in host plants, as in the case of lupins and peanuts. When Fe was limited in peanut nodules, a reduction in specific rates of nitrogenase were observed. This was an indication of a possible direct limitation by Fe deficiency on nodule function. In lupin and peanut, nodule development is much more susceptible to a shortage of iron than are other parameters such as plant shoot and root weights (Burket, 1997).

### **Manganese**

In one of the initial steps of the infection process, the binding of rhizobia to young root hairs is enhanced when *R. leguminosarum* is starved of manganese (Mn). However, it is still unknown whether Mn amounts affect the type of rhizobial exopolysaccharide (Appanna and Preston, 1987).

### **Molybdenum**

Molybdenum (Mo) is a micronutrient precisely for plants forming root nodules with nitrogen-fixing bacteria, even though non-nodule forming plants also use small amounts of Mo in a protein involved with nitrogen metabolism uptake. Molybdenum in iron (Fe) molybdenum (Mo) cobalt (Co) co-factor is at the heart of the nitrogen reduction process. The role therefore clearly depicts the relevance of this micronutrient on the  $N_2$  fixation process. Foliar application of Mo was reported to increase the levels on  $N_2$  fixation and nodule mass in grain legumes in field conditions and this has led to higher overall N content and seed yield. The bacteria; *B. japonicum* strain deficient in molybdenum transport indicated impaired nitrogen fixation activity when inoculated to soybean roots. In studies that were conducted in the laboratory, various legumes that were severely starved of Mo displayed more intense signs of

deficiency (Allen et al., 1999).

### **Nickel**

Soil nickel (Ni) application to field-grown soybean (*Glycine max* Merr.) resulted in a significant increase in nodule weight and seed yield. In some legumes, small amounts of Ni are essential for root nodule growth and hydrogenase activation. The efficiency of nitrogen fixation immediately depends on hydrogenase activity because the oxidation of hydrogen by the latter provides ATP required for the reduction to ammonia (Bertrand and de Wolf, 1967)).

### **Cobalt**

Cobalt (Co) is essential for the nitrogen-fixing microorganisms, including the cyanobacteria. Co is essential for symbiotic nitrogen fixation by legumes and non-legumes. For example, soybeans, grown with only atmospheric nitrogen and no mineral nitrogen have rapid nitrogen fixation and growth with 1.0 or 0.1..g Co ml<sup>-1</sup> but have minimal growth without Co additions. Cobalt has also been shown to be essential for *rhizobial* growth and is required as a part of bacterial enzyme complex. Cobalt deficiency affects nodule development and function at different levels and to different degrees (Ahmed and Evans, 1960).

### **Conclusion**

The inclusion of forage legumes in low-input grassland mixtures is vital to improve biomass production, forage quality and ultimately soil fertility. The improvement of forage quantity and quality is crucial for improved animal performance that is a goal of all livestock farmers. Mixing legumes and grasses serves as the forage supplementary alternative since pure grasses or cereals provide poor quality fodder due to their inherent lower crude protein content. Legume species like *Trifolium* species whose CP levels remain higher even during the driest seasons, while simultaneously partitioning the fixed nitrogen to the companion grasses are highly recommended for grass-legume mixtures. Mixing legumes with grasses increases the CP concentration of the herbage mixture relative to that of grass monocultures. This suggests that legumes have the potential to improve the diets of ruminants.

Crude protein concentrations of grasses are usually lower during the dry season (winter), therefore, forage legumes should be incorporated in sole grass stands to increase forage quantity and quality during dry seasons. Forage legumes must be used to supplement the nutritive

value of natural grasses. Legume species like *Lespedeza cuneata* can be recommended for production and baling for hay during summer and autumn for utilization during winter or early spring as, it's fibre content increases with advancing maturity. Species like *T.repens*, which, partition more of the fixed nitrogen to the companion non-legume plant and remain palatable throughout the growing seasons should be produced and grazed as standing hay. Legumes enhance carbon (C) sequestration and reduce greenhouse gas (GHG) emissions.

The C sequestration enhancement in the soil is linked to increased biomass and hence to soil fertility. The assimilation of all the biologically fixed nitrogen by a legume plant, which maintains the balance of global nitrogen cycle and keeps nitrogen in a form that does not pollute the environment, is one of the well-known benefits of biological nitrogen fixation. Intercropping forage legumes with cereals or grasses is one of the climate smart option offering a potential for increasing forage and, consequently, livestock production in many parts of the world. When developing a fodder production plan incorporating legume production the physical, chemical, biological and environmental factors affecting legume growth and development should be taken into account. These factors may impede optimum legume growth and development if not properly addressed.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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## Review

# In support of a well-planned intercropping systems in south eastern soils of Nigeria: A review

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**Soil is the medium for all crop production activities and many of the tropical soils especially soils of South Eastern Nigeria show nutrient deficiency problems after only a short period of cultivation because of the fragile nature and prevailing environmental condition. Land available for further crop production purposes in this area is very limited. To offset some of these problems and boost crop production and yields as well as economic returns, farmers use chemical fertilizers extensively on their field. These chemical fertilizers have their attendant problems ranging from non-availability, high cost, and nutrient imbalances to soil acidity. Consumers of agricultural products and farmers are getting more aware of the dangers caused by these chemicals in soil, environment, and health problems in consuming heavily chemically fertilized crops. An alternative to these chemicals is intercropping due to its environmentally friendly approach. Beside the labour management and adequate use of resources available, intercropping system promotes soil fertility maintenance, conservation and balanced nutrient which will improve crop quality and yield. It ensures farmers' flexibility, reduction against crop failures, weed control and profit maximization. This paper reviews the various contributions of intercropping system to soil fertility enhancement, nutrient recycle, and transfers among intercrop species; its effect on growth and yield of crop species as well as enlightenment on the various terms used to describe the intercropping system.**

**Key words:** Intercropping, nutrient recycle and transfer, sole cropping, soil nutrients.

## INTRODUCTION

Intercropping is a system of growing two or more crops in available piece of land and is as old as man in agricultural activities especially in tropical countries. Every peasant farmer in Nigeria practice intercropping in one form or another. They inter crop a lot of crops such as cowpea, groundnut, Bambara groundnut, melon, etc., with cassava, yam, maize, millet, sorghum, etc.

According to WGM (2003), there are a number of ways people do intercropping. In one form, crops are planted in alternating rows or strips, with the crops being kept separated, but still interacting as a result of proximity. In another, an intercrop or intercrops are planted between the rows after a main crop has started to mature. Intercrops which grow quickly can also be grown in

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several cycles while a primary crop matures. Intercropping can as well be done with crops which are totally intermixed rather than being separated. Intercropping is also known as under sowing system whereby a secondary crop or less desired crop is sown underneath the primary cash crops already established so that both will develop at the same time to cover the ground. The under sown species are always leguminous crops with the capacity of quick growing dense layer of vegetation underneath the cash crops and adds nutrients to maintain the fertility of the soil. Another terminology for intercropping is poly culture practices which involve growing of two or more plant species on the same piece of land. Depending on the plant species and their arrangement by the farmer within the farm field available, poly culture practices can take different forms. Other forms of intercropping systems are mixed cropping, cultivation of two or more crops together without any distinct row arrangement. Relay cropping is a system of planting a second crop alongside already cultivated crops at a time when the cultivated crops is at its reproductive stage or has completed its development, but before harvesting. Alley-cropping is a system of growing arable crops in alley formed by trees or shrubs, multiple cropping is a traditional farming system of growing more than one crop on the same piece of land during one calendar year.

Intercropping system takes advantage of interdependent relationships between crops with the intercrops providing shade, cover, nutrients, a trellis to grow on, and other wholesome benefits. Some crops in the intercropping may even have insecticidal and pathogenicidal effect and keep pests from vulnerable crops and suppress weeds infestation. For soils intercropping hasten soil fertility restoration and enhance soil productivity for sustainable agricultural activities. With these attributes, intercrop promotes yield and healthy crops. Onwueme and Sinha (1991) stated that among other things farmers derive yield advantage and yield stability than growing each crop separately. Thus, intercrop system can guarantee crop yield stability and bring additional income to the farmers, thereby encourage the sustainability of farming community especially with most African farmers where poverty is prevalent.

Also, decline in soil fertility from continuous cultivation on a tropical soil of which many are highly weathered, low activity clays, nutrient deficiency and nutrient imbalances, and soil acidity, makes the practice of intercropping very attractive with the poor resource farmers especially with inherent cost and non-availability of fertilizers. This has rekindled the interest of farmers in the use of natural and local (within reach) nutrient resources to build and conserve soil fertility and biodiversity management of their farm fields to sustain crop production. Thus, this review intends to report the contributions of intercropping system to improve soil productivity, crop growth, and

yield in crop production activities.

### **CONTRIBUTIONS OF INTERCROPPING SYSTEM TO NUTRIENT COMPOSITION OF SOIL, NUTRIENT RECYCLE AND TRANSFER**

Proper and adequate utilization of natural resources is the main item in practicing intercropping as the component crops are able to use natural resources to their ability differently and complementarily for the overall development of the two crops. Therefore, for success to be achieved, intercropping needs several considerations before and during cultivation. Intercropping systems according to Ibeawuchi and Ofoh (2003) limits soil losses and run-off and provides a nearly continuous cover thus preventing soil from the direct impact of the rains, and that it produces a dense and diversified root system which reduces leaching of nutrients. Gosh et al. (2006) in their study found that intercropping was beneficial for the soil microbial community of sorghum, addition of nitrogen by fixation and transferring to the cereals, and soil fertility improvement. Legume crops in intercropping system support the growth of cereal crops by improving the organic matter content and physical characteristics of the soil like structure and texture of the soil (Aslam and Mahmood, 2003). Legume-cereal inter cropping enhanced soil faunal activity resulting in more organic substrates accumulation in the soil; it could improve the soil fertility status of a less fertile soil by fixing atmospheric nitrogen and the intercrop legume will not compete with cereal crop for nitrogen resources (Gosh et al., 2006; Adu-Gyamfi et al., 2007).

Dahmardeh et al. (2010) in Iran investigated the influence of maize-cowpea intercropping on soil chemical properties and found out that intercropping increased the amount of nitrogen (N), phosphorous (P), and potassium (K) content of the intercrop maize compared to the sole maize. According to Fatokum et al. (2000), cowpea can fix up to 88 kgN/ha and in an effective cowpea rhizobium symbiosis more than 150 kgN/ha of N is fixed which can supply 80 to 90% of plants total nitrogen requirements. Ibeawuchi and Ofoh (2003) found out that the combination of base-crops and legumes intercrop generally increased soil P, soil organic matter (SOM), and soil pH, while soil N and K were reduced. Okigbo and Lal (1979) reported that relatively simple intercropping system as maize/cassava can increase the cation exchange capacity (CEC) and pH as well as increase in manganese (Mn) content in the soil. Intercropping of cotton and cowpea was found by Rusinamhodzi et al. (2006) as wonderful opportunity to improve carbon (C) sequestration and N-use efficiency in the short-term compared with monoculture. Caballero et al. (1995) and Assefa and Ledin (2001) revealed that there was competition for resources such as nutrients in the rhizosphere and light in intercropping system. Vesteraager

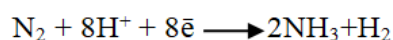


et al. (2008) observed that maize and cowpea intercropping is beneficial in nitrogen poor soils.

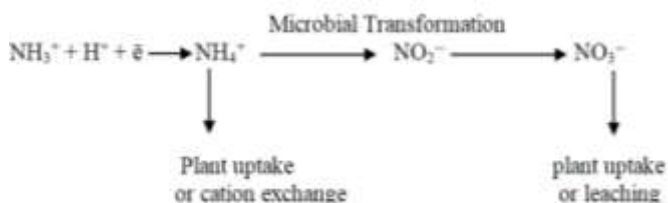
In pearl millet-cowpea intercrops, Bathiono et al. (1996) and Van der Pol (1992) reported low soil pH, k, calcium (Ca), magnesium (Mg), and CEC than the fallow system suggesting that the cropping system studied was mining the soil nutrients. Whereas Shave et al. (2012) in their studies with mucuna intercropped with maize showed positive impact on the chemical properties of soil, especially when it was introduced 6 weeks after planting (WAP) of maize and that clay, organic matter (OM), total N, P and CEC were improved by 8-14, 25-27, 43-50, 70-83, and 24-26%, respectively when compared with control, whereas sand and soil pH declined by 17-4 and 6-3%, respectively during the study. Nitrogen fixation by grain legumes in intercropping is importance as it contributes to a cereal to get higher yield and substantial amount of nitrogen in agricultural ecosystem (Cochran and Schlentner, 1995; Giller and Cadish, 1995; Izaurande et al., 1992; Giller et al., 1991; Herchel, 1987; Dakora and Keya, 1997). There was equally evidence of direct transfer of fixed N to cereal components in many controlled studies (Frey and Schuepp, 1993; Chu et al., 2004). Also, available report showed that mineralization of decomposing legumes in rhizosphere enhanced nitrogen availability of cereal crop in intercropping system (Evans et al., 2001; Dubach and Russelle, 1994; Scroth et al., 1995). When the configuration of the row are wider than the rate of N fixation activity by the legumes, Fujita et al. (1990) and Handerson and Alkins (2003) observe that the depletion of soil N by cereal stimulates legume crops to fix more N. Manna and Singh (2001) observed that coconut (*Cocos nucifera* L.) intercropped with guava (*Psidium guajava* L.) enhanced the soil microbial activities approximately 2-fold after 38 years; over 10 years of the same intercropped system, soil organic carbon (OC) increased from 38 and 10 years, respectively. Also, the report of Gosh et al. (1989) revealed that OC content of the soil was improved when cassava were intercropped with tree crops *Leucaena* and *Eucalyptus* compared to the tree crops monoculture. Even surface run off and soil erosion were effectively reduced with the intercrop due to better canopy coverage of the soil surface. Handerson and Alkins (2003) found that legume-cereal intercropping increased the fixation of N by the legumes. Maize-Cowpea intercropping was observed by Vesterager et al. (2008) to be beneficial on N poor soils and that amount of N,P,K content of the was increased compared to the mono crop maize. Intercropping control soil erosion by preventing rain drops from hitting the bare soil where they tend to seal surface pores, prevent water from entering the soil, and increase surface erosion.

Intercropping benefits non-legumes in the mixture as legumes fix nitrogen in the soil (Portes, 1989; Areioglu et al., 2003). Intercropping when properly practiced maintain high soil fertility (Opeke, 2006). Maize-Soybean intercrop

helps in efficient utilization of renewable atmospheric N since they contribute to the maintenance of soil fertility as these had been shown to be usually increased in an intercropping system (Scott and Darl, 1987). Increase in the inclusion of herbaceous and wordy forage legumes in crop production systems, improves soil structure and texture and controls erosion and supplementary browse to develop sustainable and low-input production systems (Brewbaker et al., 2012; Sumberg, 2004; Kang and Duguma, 2005). This is because legumes are notable to have symbiotic N fixing bacteria in structure called root nodules and the symbiotic bacteria called rhizobia within the root nodules of legume root systems. These bacteria have exclusive ability of fixing N from atmospheric molecular  $N_2$  into ammonia ( $NH_3$ ) as follows:



Ammonia is then converted by oxidation-reduction to the forms  $NH_4^+ + N$  and  $NO_3^- - N$ , respectively which are available and useable by plants. The first step of the reaction is that Ammonia is converted to Ammonium ( $NH_4^+$ ) and then nitrate ( $NO_3^-$ ) by the following reaction, thus:



The illustration shows the microbial transformation of N in the soil. Nitrogen in the form of ammonium ion ( $NH_4^+$ ) may be taken up by plants or adsorbed on the exchange sites, while as the nitrates ion ( $NO_3^-$ ) it may be taken by plants or leached through the soil profile. Other nutrients suffer similar fate in the soil and the reaction processes take place better in well aerated soils.

According to Wood (2006), when the legume plant dies in the field after harvesting all of its remaining nitrogen incorporated into amino acid inside the remaining plants parts and are released back into the soil, the amino are converted to nitrate ( $NO_3^-$ ) making the N available to other plants (in case a cereal crop in the intercrop), thereby serving as fertilizer for future crops in the soil. A number of studies have shown that forage and grain legume mixture increase the OM and N contents of the soil. Leguminous crops improved soil physical parameters such as texture, bulk density, moisture, and soil chemical properties and gave better protection against erosion (Nweke, 2016). The use of legumes intercropping system had been shown by Sharma and Churby (1991) to be advantageous especially in improving the N-economy of the soil by fixing atmospheric N. Total grain and plant N yield can often be increased by intercropping legumes

with non-legumes (Baker and Blamey, 1985), however, conflicting reports exist about whether a non-legume benefits from N supplied by an intercropping legume. In some instances, the N contribution of the intercropping legume to maize has been estimated to be up to 40 kg/ha (Willey, 1979), while other investigators did not find any evidence for such N benefits (Wahua and Muller, 1978). Maize-legume intercrop is wide spread. This production system has traditionally enabled farmers to cope with soil erosion and with declining levels of soil organic matter (SOM) and available N<sub>2</sub> (Scott et al., 1987).

Filho (2000) observed that intercropped maize is more competitive than cowpea in terms of use of available resources mainly soil water. Innis (1997) opined that various root systems in the soil reduce water loss, increase water uptake, and increase transpiration leading to creation of microclimate cooler than surroundings. Soil water use efficiency was observed to be the highest under soybean-maize intercropping when compared with either of the mono cropping maize or soybean (Barhom, 2001). In water scarcity, Tsubo et al. (2005) observed that soybean-maize intercropping was the best combination system during water scarcity periods. Thus, availability of water is one of the most important factors determining productivity in legume/cereal cropping systems. According to Ofori and Stern (1987), cereals and legumes use water equally and competition for water may not be important in determining intercrop efficiency except under favourable conditions. Water use by intercrop is mostly been studied in terms of water use efficiency (WUE). The work of Willey (1979) has shown that an intercrop of two crop species such as legumes and cereals may use water more efficiently than a monoculture of either species through exploring a greater total soil volume for water especially if the component crops have different rooting pattern. The WUE in a maize/cowpea intercrop was found to be higher than in the sole crops when soil water was not limiting; however, under water limiting conditions, WUE in the intercrop compared to sole maize was higher resulting in retarded growth and reduced yield. Another possible advantage of intercropping is the efficient use of soil nutrients. If both species have different rooting and uptake patterns, more efficient use of available nutrients may occur and higher total N-uptake in intercropping system compared to monoculture system have been reported by Dalal (1974), though Willey (1979) opined that it is unclear if better use of nutrient uptake is the course of the effect of higher yield potentials.

Solar radiation provides energy for photosynthesis which ultimately sets the potential for crop productivity and also determines water use by the process involved in evaporation and transpiration (Goudrian, 1982; Keating and Carberry, 1993). Photo synthetically active radiation which green plants utilize, according to Szeicz (1974) conservatively makes up about 50% of global short wave radiation compared to high variable that occurs in the

supply of water and nutrients to the plant, solar radiation is more reliable and used sufficiently by intercrops as they form a complete cover to allow full interception. Solar radiation cannot be stored for later use; it must be intercepted and utilized instantly to energize the photosynthesis process. Therefore, close plants compete for solar radiation by direct interception. Soybean and maize intercropping have been shown to have better use of solar radiation, soil nutrients, and water over the mono crop (Keating and Carberry, 1993; Willey, 1990; Morris and Garrity, 1993).

The difference between species, plant density, developmental pattern, plant height, canopy architecture, foliage overlap, and photosynthetic rate and in the assimilated reserves can cause great structural complexity in mixed-species canopies. Leaf area index (LAI) is the amount of green leaf area per unit land area, which is a parameter commonly used to describe the profitability of light interception in relation to crop canopies. Therefore, great diversity in intercrop canopies is possible according to Keating and Carberry (1993), resulting from various combination in space and time of planting date and spatial distribution, leaf size, shape and orientation, and plant height. Reddy and Willey (1981) opined that where the components of an intercrop are in direct competition for light, increased total biomass production by the crop could result in improved yield. The capturing of radiant energy drives crop evapotranspiration and the pattern of its interception determines the ratio of water use through crop transpiration to that lost in soil evaporation. N<sub>2</sub> which occurs in the atmosphere and released through decomposition of organic materials converted to ammonia by the process of biological nitrogen fixation in legume-cereal cropping system. This process is done through rhizobial fixation in legume by free-living diazotrophs. The plant furnishes the necessary energy that enables the bacterial to fix gaseous N<sub>2</sub> from the atmosphere and transfer it onto the plant for use in producing proteins. However, the quantity of N fixed by the legumes is difficult to quantify and varies with respect to the species involved and the location (Webster and Wilson, 1998). Yang et al. (2010) also observed that the radiation use efficiency of maize in intercrop 3.14 gMJ<sup>-1</sup> was slightly less than the value obtained in sole maize 3.18 gMJ<sup>-1</sup> and concluded that radiation was not a major factor in producing the competition results in maize/soybean intercropping system. Based on the fact that plants rarely compete for light without simultaneously competing for water (Cannell and Grace, 1993; Wallace, 1995).

Biological nitrogen fixation (BNF) has been exploited extensively by researchers concerned with plant nutrition in crop production practice studies which emphasized on environmental sustainable development on the use of renewable resources including the role of BNF for supplying N for agriculture (Peoples and Craswell, 1992).

The subject of BNF is of plant practical importance because the use of nitrogenous fertilizers has resulted in unacceptable level of water-pollution increasing concentration of toxic nitrates in drinking water supplies and the eutrophication of lakes and rivers, soil acidity and nutrient imbalance resulting in not only a waste of energy and money, but also leads to serious pollution problems. Nitrogen fixation is an energy demanding process and is dependent on photosynthesis (Bech et al., 1985). Therefore, if the intercrop non-legume is taller than the legume crop, shading will occur and photosynthesis and subsequently  $N_2$  fixation will be reduced (Wahua and Muller, 1978), plant density also has an effect on  $N_2$  fixing activity. A reduction of  $N_2$ -fixation per plant at increasing plant density has been reported by Haidy and Huelka (1976) and bulk total  $N_2$ -fixing activity per area appeared to be less variable (Haidy and Huelka, 1976). The value compiled by Peoples and Harridge (1990) and Peoples and Craswell (1992) showed that the rate of N fixation by a range of legumes varies between 5 and 300 kg N/ha/year with an average of about 100 kg N/ha/year. The amount of biological fixed  $N_2$  that is actually taken up by the main crops is difficult to determine with accuracy.

Ofori and Stern (1986) opined that in cereal-legume intercropping, BNF sole crops without applied N, large application results in excessive vegetative growth of cereal, causing it to shade and suppress the legumes yield; also similar observation was made on melon intercrop where seed yield was significantly reduced by 25 kg/ha. Stern (1993) opined that conflicting reports exist about the transfer of N from legumes to cereals intercropping studies. Nitrogen transfer refers to the movement of biologically fixed nitrogen from the legume crop to the non-legume crops and encompasses interactions within the soil OM, reduced into a mineral form, directly taken up the companion crop or lost from the system and one affected by physical and biological factors at that time. This as was revealed by Ofori and Stern (1987) can be directly transferred to the companion non-legume crop residually available to the subsequent crops. The mechanism of the transfer depends on the species, proportion of component crops in the stand, relative maturities of the associated crops and their vigour and duration of growth. Harridge et al. (1994) emphasized that a problem faced by farmers everywhere is that the capacity of soils to supply N declines rapidly once agricultural activities commence and N derived from the breakdown of soil matter must be sustainable production,  $N_2$  reward must be replaced by N fertilizer.

The movement of fixed N from legume to the companion crop during the current growing season is said to be direct N transfer (Stern, 1993), however, an assumption exists stating that a portion of  $N_2$  fixed by an intercropping legume is more available to an associated non-legume crops during the growing season. Depending on the biomass of the legume crop, Stern (1993) stated that mycorrhiza can help on the direct transfer of N from

plant to plant because intercropping is one season duration (annual), Peoples and Harridge (1990) argued that direct transfer of N from legume to non-legume might not be a rapid or spontaneous phenomenon. Ofori and Stern (1987) observed no direct transfer from cowpea or rice bean (*Vigna umbleleta*) to maize. When the fixed N becomes subsequently available to the companion non-legume crop during the current season it is referred to as indirect N transfer (Stern, 1993). Decaying of roots and nodules are thought to be an important factor that determines the N transfer, generally, there is a small amount of N transfer during a current season and most movement occurs during the end of the legume crop cycle. The proportion of root system that might be decomposing during growth has not been estimated (Peoples and Craswell, 1992). The possibility also exists that N exudation from roots should not be ignored (Poth et al., 1986). Indirect transfer of N has been reported by Eaglesham et al. (1981), but it was not confirmed by Ofori and Stern (1987). Nitrogen contribution of legumes in the intercropping is very vital for maintaining soil productivity over long periods.

The nature and manner of root spread in soil among the intercrops determines the uptake of water and nutrients and their utilization. Root distribution among intercropping plays an important role in interactions between the intercrop species. Studies of Zhang et al. (2002), Zhang and Huang (2003), and Lie et al. (2006) investigated root distribution in intercropping system and found out that yield advantages of the intercropping system are due to both aboveground and belowground interactions between intercrop species and when the roots of the two crops does not overlap it reduced competition for water and nutrients between the two crops which results in higher yields. Zhang et al. (2002) investigated the root distribution in wheat/faba bean intercrop and observed that the growth stages of the two crops when root weight is maximum did not overlap, reduced the competition between the maize and faba bean for nutrients and water which resulted in higher yields of both crops. Root distribution in a maize/cabbage intercropping system showed clearly unbalanced distribution according to the observation of Zhang and Huang (2003), with the roots of maize extending horizontally to greater distances than those of cabbage, while Adiku et al. (2001) in their own studies were able to discover that the roots of maize and cowpea has extended into the rhizospheres of each other but the encroachment on part of maize was much greater. This scenario definitely affects the uptake and utilization of water and nutrients of both crops. Lie et al. (2006) observed that the roots of maize penetrated deeper than those of the faba bean and spread under the faba bean strip in a maize/faba bean intercropping system. In intercropping system, availability of soil water and all that dissolve there in are the limiting factor to the roots arrangement and distribution in soil. Roots tend to grow

profusely into all sections of soil when water is not a limiting factor, but under water stress they clump within their own zone and under severe water stress the roots do not intermingle at all (Ozier-lafontaine et al., 1998; Adiku et al., 2001; Lie et al., 2006). Root distribution in intercropping therefore influences strongly water and nutrient uptake and invariable the yield of the component crops. Yang et al. (2010) attributed the difference in grain yield and N uptake of maize in maize/soybean intercrop to faster development and deeper reach of maize roots and a higher N uptake capacity under non-limiting conditions. The inconsistency of cereal and legume intercropping performance requires critical investigation in areas where farmers are to benefit from intercropping in that specific locality (Mpangene et al., 2004), like the south eastern soils of Nigeria that are suffering from various degrees of degradation and the farmers are poor.

#### **CONTRIBUTIONS OF INTERCROPPING TO THE SOIL, GROWTH AND YIELD OF INTERCROPPED SPECIES AND EFFICIENT UTILIZATION OF ENVIRONMENTAL FACTORS**

Many researchers have explored the use of intercropping system for forage production and quality. Maize/Cowpea intercropping system resulted in significant effect on forage dry weight and digestive dry matter yield and amino protein content was increased by intercropping when compared with maize and cowpea sole crops (Dahmardeh et al., 2007), significantly higher crude protein content of maize-soybean intercropping than that of mono-cropped maize (Toniolo et al., 1987). The authors showed that the result was related with higher consumption of environmental resources such as photosynthetic active radiation and soil moisture by intercropping. Maize forage quality in terms of crude protein was improved by intercropping. It was probable because of more nitrogen availability for maize in intercropping compared with its sole crop. Javanmard et al. (2009) worked on intercropping of maize with different legume; their findings showed that dry matter yield and crude protein yield of forage were increased by all intercropping compositions as compared to the maize mono culture. Intercropping system is an important factor that influences the quantity of N fixed by legumes (Rerkasem et al., 1988). However, the differences in the depth of rooting and spread of the intercrops, lateral root and rooting densities are some of the factors that affect competition between the component crops in an intercropping system for water and nutrients. In this regard, Carr et al. (1998) and Carruthers et al. (2000) in their studies found cereal component maize to be competitively advantageous for soil nitrogen as compared to the component crop in the intercropping because the cereal is taller, has faster growing and more extensive root system particularly a large mass of fine roots. This

competition for N forces the legume component cowpea according to the work of Jensen (1996) and Huaggard et al. (2001) to fix nitrogen from the atmosphere. This effectively influences the growth and yield of the intercrop components as maize and cowpea benefit from the biological fixation of atmospheric N. This scenario will end in more uptakes of N and crude protein content in maize intercrop compared to the sole maize. The forage quality of maize was improved by intercropping due to more nitrogen availability for maize in intercropping. Intercropping system is an option for diversification of crop production system by increasing the number of cultivated crop species in the same piece of land; this is usually justified by the better use of environmental resources as compared to mono cultures (Vandermeer et al., 1998). Intercropping advantages include higher yield and yield stability and more efficient use of environmental resources, probably due to less intra-specific competition between the intercrops which is also an insurance against crop failure (Viljoen and Allemann 1996). This is a more balance food supplies for both human and livestock. Yang et al. (2010) found out that grain yield and N uptake of maize in intercrop were significantly greater than those of sole maize and grain yield of soybean as an intercrop which is significantly lower than sole soybean and their N uptake relatively, thus indicating that intercropping favoured nutrient uptake and growth of maize and the growth of soybean significantly.

According to Ghaffarzadeh et al. (1997), the basic ideas are based on how different species interact during intercropping competition for resources which arise from varying time of planting, root growth patterns and different resource demands. At high levels of N, under intercropping, Ezumah et al. (1987) and Ofori and Stern (1987) observed that grain and legume yield was reduced by the maize intercrop. The decrease in maize yield under intercrop was also reported by Shumba et al. (1990). Faulkner (1994) estimated that the increase in yield of a maize crop following a mucuna crop or cowpea or groundnut was in the order of 200 to 900 kg/ha. Agboola and Fayemi (2001) investigated maize/*Mucuna pruriens* intercrop and observed that maize yield was reduced but intercropping with *Calopogonium mucunoides*, groundnut, pigeon peas did not affect the maize yield, their studies equally indicated that *C. mucunoides*, groundnut, pigeon pea and cowpea fixed 370 kg N/ha when intercropped with maize. Maize-potato intercropping performed better than the sole potato as was observed by Begum et al. (1999) and in maize-okra intercropping Muoneke and Asiegbu (1997) observed that yield and yield components of okra was increased. Sharma and Tiwani (1996) reported that maize/tomato intercrop increased the number and weight of fruit. The mixtures of cereal and legumes produce higher grain yield than crops grown individually or together; in such crop mixtures the yield increases were not only due to enhanced N nourishment of the cereal component, but

also to other unexplored causes, thus intercropping ensures yield stability (Onwueme and Sinha, 1991). Alom et al. (2009) observed that maize yield under intercropping was higher than that of mono crop, though the population of maize was constant regardless of the intercropping and pod yield of groundnut in the intercropping situation was considerably reduced. On the contrary, Nweke et al. (2013) investigated the intercropping system of ground/maize/okra and observed that the intercropping system did not influence the plant height, number of leaves and number of branches and that groundnut sole crop recorded the highest value in these parameters when compared with the intercrops. Equally the yield of pods of groundnut was the highest in sole cropping compared to groundnut-maize-okra intercropping and conversely, the values of weight of pod obtained from groundnut-maize-intercrop and groundnut-maize-okra intercrop were also similar which indicated that the effect of intercropping system were not effective in the intercrop. Addo-Quenye et al. (2011) reported the reduction in cob growth and net assimilation rate in maize/soybean intercrop, where shaded by already established soybean. Atilola (2007) revealed in his study that there was non-significant effect of groundnut intercropped with maize on growth and yield parameters of groundnut. In maize/cowpea intercropping, Dahmardeh et al. (2010) found increased yields of cereal succeeding cowpea. Pod weight of brinjal in brinjal/groundnut intercropping was low in mono culture compared to intercrop and reddish vegetable amaranths intercropping indicate yield advantages from intercropping compared to mono cropping (Prasharanth et al., 2009; Seren and Brintha, 2009). Ennih et al. (2002) revealed that there was increase in plant height reduced number of branches, leaves and leaf area index of soybean when inter cropped with maize, Chiezey et al. (2004) found no significant response to crop arrangement in number of days to 50% flowering in soybean or sorghum grown as intercrops. Quayyum and Maniruzzaman (1995), Nag et al. (1996) and Uddin et al. (2003) opined that higher yield of maize was obtained in the mono culture as compared to the yield of intercropping of groundnut. They attributed the result to no intercrop competition for light, moisture and space. The result of Koli (1975) on pure and mixed cropping of maize and groundnut in Ghana showed that yields of groundnut in the mixed intercropping were from one third to one half the yields obtained from the pure culture but the yield of maize was not reduced to the same extent. Similarly, Khatiwada (2000) found cauliflower in maize intercrop produced 7 t/ha cauliflower in conjunction with 2.1 t/ha maize. Seran and Jegakumaran (2009) however reported lower number of pods per capsicum plant in capsicum-vegetable cowpea intercropping compared to mono cropping probably due to nutrient and light competition. Cereal-legume intercropping is superior to mono cropping, maize/French bean gave higher maize equivalent yield over sole maize

yield (Hugar and Palled, 2008) and Kernel yield of maize was unaffected in maize-French bean intercropping (Hugar and Palled, 2008). The study of Akinmfesi et al. (2006) revealed that without N fertilizer application, gliricidia-maize intercropping gave high maize yield. In maize-bean intercropping, Tsubo et al. (2005) found maize yield not affected by the production system. Cassava/Maize intercrop yield better than the component crops due to greater biological advantages over sole cropping and temporal complementarity of those species. Muoneke et al. (2001) reported yield reduction in Roselle/cowpea intercrop and the reduction was the highest when intercropped with Roselle planting density of 37,000 Roselle plant/ha. The authors attributed yield reduction to competition for growth resources as reported in other crops in mixtures by other various workers (Willey, 1979; Muoneke and Asiegbo, 1997). Ikeh et al. (2013) noted yield increase in water yam/vegetable cowpea. An increase of 64 to 84% of ware tubers (tubers of 1 kg and above) was recorded over what was obtained from sole cropped yam; however, they found non-significant difference between both cropping systems in sprouting percentage and in numbers of leaves per plant in all the month under study. High leave retention of 32.17 and 65.92 over sole crop of 23.87 and 57.17 was recorded at 2 and 3 months after planting.

Onyekwere et al. (2013) observed that all the leguminous food crops, namely, pigeon bean, groundnut, and vegetable cowpea intercropped with *Dioscorea dumetorum* and maize gave significantly ( $P < 0.05$ ) higher yield than sole *D. dumetorum* and that of *D. dumetorum*/maize intercrops, with the highest yield value obtained from *D. dumetorum*/maize/groundnut. Thelma (2002) and Esekhide et al. (2003) found out that intercropping rubber with arable crops had growth and yield advantages and capable of increasing the returns of the rubber enterprise. In a four-year study of rubber and cassava intercropping, Esekhide et al. (2013) found yield of rubber to be zero of which they attributed it to have not attained tappable maturity, but the yield of cassava in the intercrop was superior to the sole crop with a value of 2.19, 42.80, 19.44, and 19.44 t/ha of cassava tuber for 1, 2, 3, and 4 years, respectively as against sole crop of 20.90, 37.73, 16.52, and 16.52 t/ha of cassava tuber in 1, 2, 3, and 4 year, respectively. Singh and Sharma (1987) evaluated yield stability in intercropping in India and found out that intercrops gave additional yields and increased the net returns.

Adetiloye and Adekunle (1989) working in Southwest Nigeria, reported that intercropping of cassava-maize-cowpea gave higher agronomic yield advantage than any of the crops planted in pure culture. Although, the total productivity of an intercropping system can be greater, Rees (1986) observed that the productivity of at least one or even both component crops is usually less than that of respective sole crops in popular binary system. Roy et al. (1990) reported fibre yield reduction in Roselle

intercropping with black gram, cowpea, soybean, groundnuts, and sesame. Samsri et al. (1987) work on groundnut/Roselle intercropping and reported yield reduction. Roselle a fibre crop, the fibre yield, was found to be reduced by 4 to 18%. In groundnut/sorghum intercropping, a yield reduction of 50 to 52% in groundnut was reported (John et al., 1943) and higher yield increase was obtained from intercropping than sole cropping. In an experiment conducted by Evans (1960) in East Africa, almost all experimental combinations of groundnuts with sorghum recorded positive benefits as the combinations gave yield advantages as high as 38% (Rao and Willey 1980), while yield advantages up to 57% was already reported by Tarhalkar and Rao (1979). Anthony and Wilmott (1957) reported higher yield from groundnut and cotton intercropped together. Evans and Sreedharan (1962) and Tarhalkar and Rao (1975) worked on castor bean/groundnut intercropping and found out that the intercrop performed exceedingly better and higher monetary returns was higher than what was obtained from pure castor crop. Increasing maize density three-fold from 18,000 to 55,000 plants/ha caused reduction of 24% in leaf area index and 70% in seed yield of the associated bean (Gardiner and Cracker, 1981). Addo-Quaye et al. (2011) recorded higher yield in sole maize than the intercropped maize in a study of maize/soybean intercropping system as affected by time of planting and spatial arrangement. They attributed the reduction in the yield of the cereal component of the intercrop to inter-specific competition and shading of maize seedling by the already established soybean plants that led to reduction in leaf area, crop growth rate, and net assimilation rate (Caballero et al., 1995; Assefa and Ledin, 2001; Misbahulummir et al., 1989; Addo-Quaye et al., 2011). Alom et al. (2009) investigated performances of different hybrid maize (*Zea mays* L) varieties under intercropping systems with groundnut (*Arachis hypogaeu* L) and found out that all yield and yield components of hybrid maize were significantly influenced by maize/groundnut intercropping system in the years under study. The grain yield of maize showed almost similar pattern to its yield contributing characters observed in sole and at different intercropping system studied though the result of their maize yield was found to be higher in monoculture compared to their yield in intercropping situation of which they attributed to no intercrop competition for light, nutrients, moisture, and space. Their findings corroborated with the works of Uddin et al. (2003), Nag et al. (1996), and Quayyum and Maniruzzaman (1995). The shading effect of maize on the groundnut according to the authors contributed considerable to the reduced pod yield observed in the intercropping situation of which similar results were reported by Razzaque et al. (2007) and Karim et al. (1990). Nweke (2015) however, found higher grain yield in intercrop than sole crop of which the percentage increase in grain yield per plot over sole crop on the average was 28.6% when he investigated the

effect of intercropping panicum maximum with maize.

## CONCLUSION

Intercropping cost effective and eco-friendly with the advantage of intercropping species together; and their associated microbes has many advantages over sole cropping. Intercropping system can be an excellent sources of bio fertilizer especially when leguminous crop is used, of which their addition improves the biophysical, biochemical and physiochemical and biological properties of agricultural soil. Although, there are some insinuations and challenges that intercropping systems is not well adapted to dry, poorly drained and heavy clay soils and difficult in mechanisation such as in sowing, weeding, fertilizer application, and harvesting. Hence, intercropping on large scale using machinery is generally believed to be impossible. These challenges not withstanding adequately planned and full implementation of intercropping system can act as a panacea for soil fertility enhancement, soil reclamation, crop growth and yield and for sustainable agriculture in south eastern soils of Nigeria.

## CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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*Full Length Research Paper*

# **Adaptability and genotype-environment interaction of finger millet (*Eleusine coracana* (L.) Gaertn) varieties in North Eastern Ethiopia**

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An experiment was conducted to study the adaptability and genotype × environment interaction of finger millet varieties in the north eastern part of Ethiopia. Eight finger millet varieties and a local check were tested at Sirinka, Kobo, and Jari in 2013 and 2014 cropping season. The experiment was laid out in a randomized complete block (RCB) design with three replicates. The result showed that the year 2013 was relatively better than 2014 for finger millet yield. Variety Bareda ranked first in terms of yield at Sirinka both in 2013 and 2014 (SR13 and SR14), and Kobo in 2013 (KB13). Variety Tadesse ranked first at Jari in 2013 (JR13); however, both the local check and Gute ranked first at Jari in 2014 (JR14). Except at JR14, the local check ranked second in all the environments. The Additive Main-effect and Multiplicative Interaction (AMMI) analysis showed that the best fit model was AMMI1 and it explained 68.54% of the genotype × environment interaction. Genotypes Bareda, the local check and Gute had higher grain yield in that order. Similarly, environments SR13, JR13 and KB13 had above average grain yield. Varieties Tadesse and Padet had small interaction effect; however, Bareda and Gute exerted relatively higher interaction effect. Similarly, environment SR13 contributed minimum interaction effect; whereas KB13 and JR13 contributed higher interaction effect. Genotype and genotype × environment (GGE) biplot identified the local check, Bareda and Gute as more desirable varieties. Based on the overall performance and adaptability of the finger millet varieties across environments, Bareda could be recommended for production at Sirinka and Kobo, whereas the local check could still be used at Jari.

**Key words:** Adaptability, additive main-effect and multiplicative interaction (AMMI), *Eleusine coracana*, G × E interaction, genotype and genotype × environment (GGE).

## **INTRODUCTION**

Finger millet (*Eleusine coracana* (L.) Gaertn), believed to be adapted to the arid and semi-arid regions of the world, is highly tolerant to pests, diseases and drought (Gowda

et al., 2015). It serves as a food and nutritional security crop because of its adaptability to a wide range of environments, high nutritional value, excellent storage

**Table 1.** Description of the finger millet experimental sites.

Location	Altitude (m)	Soil type	Rainfall (mm)	Temperature (°C)		Global position	
				Min.	Max.	Latitude	Longitude
Kobo	1450	<i>Eutric fluvisol</i>	637	15.8	29.1	12°8'21"	39°18'21"
Sirinka	1850	<i>Eutric vertisols</i>	945	13.6	27.3	11°45' 00"	39°36'36"
Jari	1680	<i>Vertisol</i>	NA	NA	NA	11°21'	39°38'

Source: Sirinka Agricultural Research Center. NA: Not available.

qualities and its importance as a low input crop (Dida et al., 2007). It is cultivated on more than 31 million ha of land globally (FAO, 2014).

Finger millet straw is used for livestock feed in many countries, however, it is mainly grown for food (Upadhyaya et al., 2006) and also for brewing of gluten free beverages (Shayo et al., 2001; Fernandez et al., 2003; Bano et al., 2015). Finger millet grain is nutritionally rich as it contains high levels of protein and minerals (Upadhyaya et al., 2006). David et al. (2014) reported that the proximate composition of finger millet to be moisture (6.99%), ash (2.37%), crude protein (10.28%), crude fibre (3.10%), crude lipid (0.83%), carbohydrate (76.43%) and mineral like potassium (14.19 mg/g), sodium (6.86 mg/g), copper (0.10 mg/g), calcium (1.13 mg/g), magnesium (6.25 mg/g), zinc (0.22 mg/g), manganese (0.32 mg/g), iron (0.11 mg/g) and lead (0.001 mg/g). It contains appreciable amount of the essential amino acid methionine which is lacking in most food grains (National Academies, 1996). Finger millet is suitable to design and develop value-added nutritive food products. Woldemichael and Admasu (2017) reported germination to be effective in starch and protein hydrolysis; while fermentation was more effective in reducing phytate, consequently increasing mineral bioavailability.

In Ethiopia, finger millet is produced by 1.6 million farmers on 454662.33 ha of land (CSA, 2014). Appreciable variability in Ethiopian finger millet genotypes has been documented by various workers (Bezawele et al., 2006; Lule et al., 2012; Wolie, 2013). Although about 15 improved finger millet varieties have been developed in Ethiopia (MoANR, 2016), and some of these varieties were tested for adaptability and introduced to farmers in the north western part of Ethiopia (Fentie, 2012); the use of these varieties in the north eastern part of Ethiopia is not common. Hence, there is a need to study the adaptability of finger millet varieties in order to recommend varieties in that part of Ethiopia. The objectives of this experiment were to identify adaptable improved finger millet varieties and to assess the

magnitude of genotype-environment interaction in north eastern part of Ethiopia.

## MATERIALS AND METHODS

The experiment was conducted on three locations for two years, 2013 and 2014. The locations were Sirinka, Kobo and Jari, which represent the finger millet growing areas of North Eastern Ethiopia (Table 1).

Eight finger millet varieties were included in the study and a local (farmers') variety was also added for comparison. The eight varieties were released in Ethiopia by three different agricultural research centers (ARCs). Varieties Necho and Degu were released by Adet ARC in 2011 and 2005, respectively; Bareda and Gute in 2009, Wama and Boneya in 2007 and 2002, respectively, by Bako ARC; Padet and Tadesse in 1999 by Melkassa ARC. The experiment was laid out in a randomized complete block (RCB) design with three replicates. A plot size of 5 rows × 40 cm × 5 m was used, and a space of 1 m between plots and 0.5 m between blocks was also left. Seeding rate was 20 kg/ha. Nitrogen and phosphorus fertilizers, as Urea and DAP, were applied at the rate of 50 kg/ha urea and 100 kg/ha DAP. Weeding was applied as the case may be, uniformly to all the plots. Data were collected both on plant and plot basis for phenological, yield and agronomic traits.

In 2013, data were recorded from the three locations. In 2014, however, data were recorded from Jari and Sirinka only, as the experiment at Kobo was failed due to deficit moisture stress and grass hopper attack. Additive Main-effect and Multiplicative Interaction (AMMI) analysis was done based on Zobel et al. (1988); genotype and genotype by environment interaction (GGE) analysis was done as per Yan et al. (2000). Analysis of variance, AMMI and GGE analyses were carried out by using GenStat (16th edition) software.

## RESULTS AND DISCUSSION

The results of the combined analyses of variance across locations for 2013 and 2014 are depicted on Tables 2 and 3. The year 2013 was relatively better than 2014 for finger millet yield, as evidenced by higher yield in 2014. In 2013, the location effect was significant ( $P \leq 0.01$ ) for all the traits considered. However, genotypes (varieties) and G × L interaction term differed significantly for days to

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**Table 2.** Mean grain yield and other agronomic traits of finger millet varieties tested at three locations in 2013.

Variety	Days to heading	Days to maturity	Plant height (cm)	Grain yield (ton ha <sup>-1</sup> )
Degu	88.9	135.9	93.89	2.84
Gute	82.4	127.2	87.67	3.56
Wama	83.7	126.7	88.89	3.46
Local	84.3	128.7	86.00	3.72
Necho	87.8	132.6	90.56	2.44
Padet	81.1	126.1	86.78	3.14
Bareda	82.4	127.8	90.56	3.80
Boneya	81.8	125.9	85.67	3.50
Tadesse	81.6	125.9	90.00	3.67
Mean	83.8	128.5	88.89	3.35
LSD (5%)	1.7	2.2	7.45	0.59
CV (%)	2.1	1.8	8.9	18.6
Genotype (G)	**	**	NS	**
Location (L)	**	**	**	**
GxL	**	**	NS	**

\*\*Significant at 0.01 probability level. NS: Non-significant.

**Table 3.** Mean grain yield and other agronomic traits of finger millet varieties tested at two locations in 2014.

Variety	Days to heading	Days to maturity	Plant height (cm)	Grain yield (ton ha <sup>-1</sup> )	Thousand-grain weight (g)
Tadesse	80.2	128.8	89.30	2.63	29.00
Padet	81.5	129.5	91.37	2.62	29.50
Necho	89.2	143.5	89.23	2.74	22.83
Degu	90.2	144.2	83.77	2.00	21.50
Boneya	78.8	130.2	93.67	2.52	28.67
Wama	80.2	133.3	93.90	2.65	32.00
Gute	83.2	134.5	101.23	2.88	34.33
Bareda	82.7	134.8	95.40	2.79	32.33
Local	78.7	131.2	84.20	2.85	23.50
Mean	82.7	134.4	91.34	2.63	28.18
LSD (5%)	1.7	2.4	8.01	0.62	3.71
CV (%)	1.7	1.5	7.5	20.0	11.2
Genotype (G)	**	**	**	NS	**
Location (L)	*	**	**	NS	**
GxL	NS	**	NS	NS	NS

\*\*, \*Significant at 0.01 and 0.05 probability levels. NS: Non-significant.

heading and maturity, and grain yield. In that same year, varieties Degu and Necho were late to flower and to mature; however, the rest were comparatively early to flower and to mature. Bareda, the local variety and Tadesse were the high-yielding varieties (Table 2).

In the year 2014, varieties differed significantly ( $P \leq 0.01$ ) for days to heading and maturity, plant height and 1000-grain weight. Similarly, the location effect was significantly different for all the traits considered except grain-yield. The G × L interaction term was significant only for days to maturity. Like the year 2013, Degu and

Necho were late to flower and to mature in 2014 also. Gute was the tallest variety. As evidenced by higher 1000-seed weight, varieties Gute, Bareda and Wama were bold-seeded varieties as compared to the others (Table 3).

Location and year combinations were considered as environments shown in Table 4. Bareda was the highest yielder in the high-yielding environment (SR13). Similarly, Gute and the local check were the highest yielders in the low-yielding environment (JR14). Bareda ranked first at Sirinka and Kobo (SR13, SR14 and KB13) in terms of

**Table 4.** Mean grain yield (ton ha<sup>-1</sup>) of nine finger millet varieties grown in five environments (location and year combinations).

Variety	Environment				
	JR13	JR14	KB13	SR13	SR14
Tadesse	3.65	2.74	3.41	3.61	2.85
Padet	2.98	2.68	3.02	3.35	2.65
Necho	2.80	2.46	1.90	2.92	2.70
Degu	3.11	2.08	1.95	3.23	2.17
Boneya	3.26	2.44	3.39	3.54	2.91
Wama	2.88	2.73	3.36	3.91	2.79
Gute	3.28	2.97	3.74	3.52	2.95
Bareda	3.18	2.83	3.89	4.01	3.07
Local	3.39	2.97	3.73	3.79	2.98
Mean	3.17	2.66	3.15	3.54	2.79

JR13: Jari 2013; JR14: Jari 2014; KB13: Kobo 2013; SR13: Sirinka 2013; SR14: Sirinka 2014.

**Table 5.** The AMMI analysis of variance table for grain yield of nine finger millet varieties on five environments.

Source	df	SS	MS	SS explained (%)
Total	134	90.82	0.678	-
Treatments	44	57.12	1.298**	-
Genotypes	8	13.23	1.654**	23.16
Environments	4	20.97	5.242**	36.71
Interactions	32	22.92	0.716**	40.12
IPCA 1	11	15.71	1.428**	-
IPCA 2	9	3.55	0.394	-
Residuals	12	3.67	0.306	-
Error	80	22.95	0.287	-

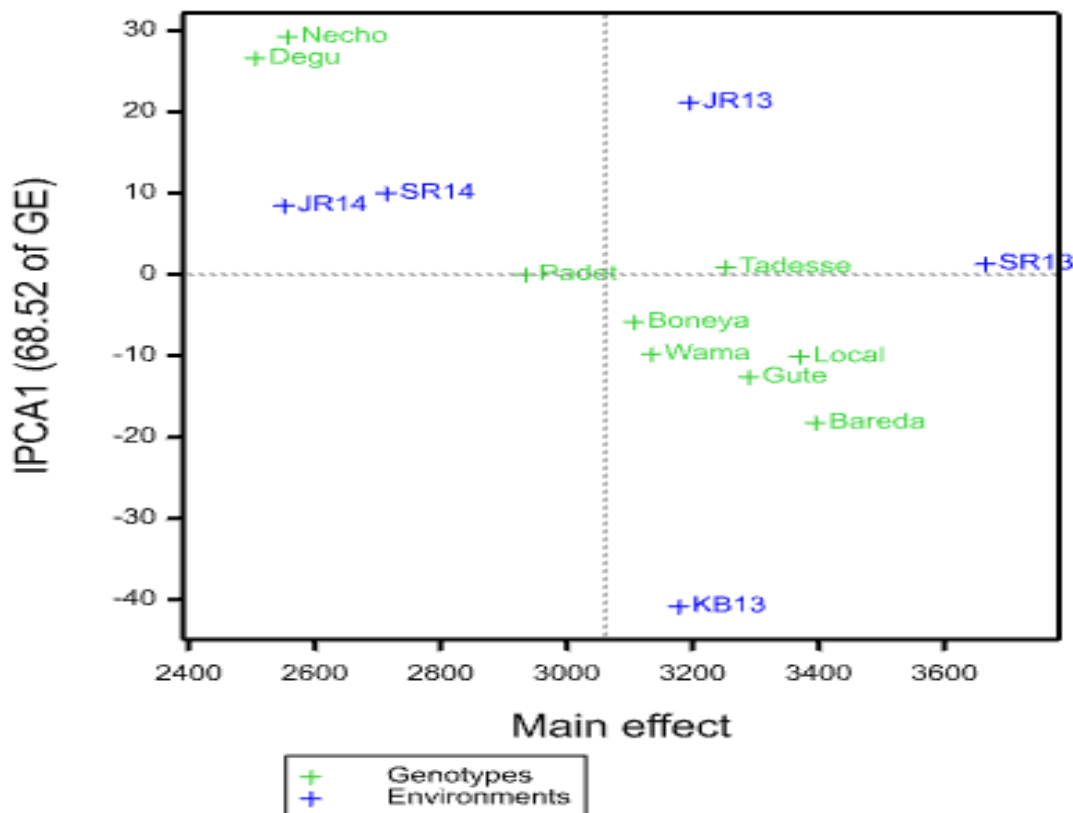
\*\*Significant at 0.01 probability level.

yield. Tadesse ranked first at JR13; however, both the local check and Gute ranked first at JR14. Except JR14, the local check ranked second in all the environments (Table 4).

The AMMI model combines AOV with additive parameters and PCA with multiplicative parameters into a single analysis (Gauch and Zobel, 1997). The AMMI and GGE analyses were based on five environments. The AMMI analysis demonstrated that genotype, environment, and G × E were significant ( $P \leq 0.01$ ). Genotype, environment, and G × E explained 23.16, 36.71 and 40.12% of the total treatment variation (Table 5). Fentie et al. (2013) demonstrated 59.64, 9.61 and 30.75% of the total variation in finger millet grain yield to be accounted for by environment, genotype and G × E, respectively. In a mixed and colored sets of finger millet types, Adugna et al. (2011) reported 2.5, 79.1 and 18.3% of the total sum of squares in the mixed set and 2.1, 86.9 and 11.0% in the colored set to be attributed to genotype, environment, and G × E interaction effects, respectively. In a study of

15 finger millet genotypes under three environmental conditions, Misra et al. (2009) explained 7.88, 79.69 and 13.43% of the treatment variation in yield by genotype, environment and G × E, respectively. From the sources of variation of treatments, the genotype and interaction sources affect genotype rankings within environment and hence are relevant for targeting genotypes; these relevant effects account for 10 to 40% of the treatment variation (Gauch and Zobel, 1997). In the study, the treatment sum of squares (SS) was 57.12. However, the relevant portion of this SS was only 36.15 (genotype SS + interaction SS) or 63.29% of the treatment SS (Table 5).

According to Gauch and Zobel (1997), in addition to the environmental effect, errors from uncontrolled variation within experiments are also irrelevant and should be removed from the interaction. Accordingly, from the interaction SS, 9.184 (the product of 32 and 0.287) was the real structure SS. As a result, the relevant variation was only 26.97 (13.23+13.74) or 47.21 % of the treatment



**Figure 1.** AMMI biplot of main effects of finger millet genotypes and environments, and IPCA1 using symmetrical scaling. JR13: Jari 2013, JR14: Jari 2014, KB13: Kobo 2013, SR13: Sirinka 2013, SR14: Sirinka 2014.

SS, the rest would be irrelevant environment effect and interaction noise.

The AMMI analysis showed that the best fit model was AMMI1 in this experiment, as only the first interaction principal component axis (IPCA1) was significant ( $p < 0.01$ ). The IPCA1 explained 68.54% of the  $G \times E$  interaction SS (Table 4). In agreement to the present investigation, Misra *et al.* (2009) demonstrated that the significant IPCA1 accounted for 93% of the total  $G \times E$  interaction sum of squares. However, Wolie (2013) reported 61.22% of the  $G \times E$  to be explained by the first two significant IPCAs. In mixed and colored finger millet sets of experiments, Adugna *et al.* (2011) explained 54.6 and 46.19% of the  $G \times E$  sum of squares in the mixed and in the colored set, respectively, by the first two IPCAs. Similarly, Lule *et al.* (2014) explained 88.32% of the total  $G \times E$  interaction in 32 finger millet genotypes by IPCA1 (66.05%) followed by IPCA2 (12.81%) and IPCA-3 (9.46%).

In the biplot system, main effects (both genotypes and environments) and IPCA1 (interaction) are used as abscissa and ordinates (Zobel *et al.*, 1988; Gauch, 1992). The AMMI biplot showing the main and IPCA1 effects of both genotypes and environments on finger millet grain

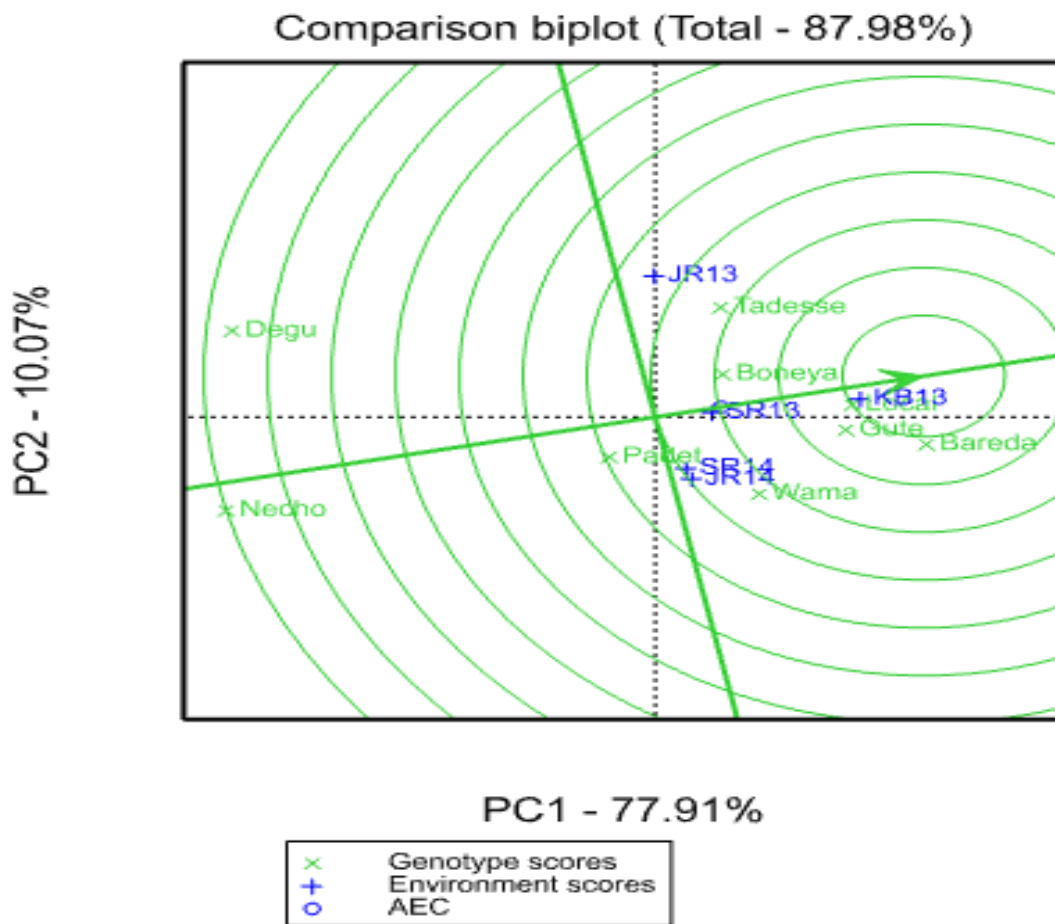
yield is as shown in Figure 1. As shown in Figure 1, distances along the abscissa show main effect differences, whereas the ordinate shows differences in interaction. In the present study, the AMMI1 biplot showed that genotypes Bareda, Local check and Gute had higher grain yield in that order; however, genotypes Padet, Necho and Degu had below average grain yield. The IPCA scores of genotypes in the AMMI analysis indicate the stability or adaptation over environments (Gauch and Zobel, 1996).

Similarly, environments SR13, JR13 and KB13 had above average grain yield; whereas, SR14 and JR14 had below average grain yield. Varieties Tadesse and Padet had small interaction effect; however, Bareda and Gute had relatively higher interaction effect. Likewise, SR13 contributed minimum interaction effect, whereas, KB13 and JR13 contributed higher interaction effect (Table 6 and Figure 1).

The GGE biplot is useful for identification of mege-environments, ideal genotype and test environments, among other things. Figure 2 shows the average-environment coordination (AEC) view of ranking genotypes relative to an ideal genotype. The center of the concentric circles pinpoints the ideal genotype, a

**Table 6.** Finger millet genotype and environment means, and G× E interaction scores.

NG	Genotype and environment	Mean yield (ton h <sup>-1</sup> )	IPCA1
<b>Genotype</b>			
1	Bareda	3.40	-0.578
2	Boneya	3.11	-0.186
3	Degu	2.51	0.841
4	Gute	3.29	-0.399
5	Local	3.37	-0.320
6	Necho	2.56	0.924
7	Padet	2.94	0.000
8	Tadesse	3.25	0.028
9	Wama	3.14	-0.310
<b>Environment</b>			
1	JR13	3.20	0.669
2	JR14	2.55	0.267
3	KB13	3.18	-1.292
4	SR13	3.67	0.040
5	SR14	2.72	0.315



**Figure 2.** GGE biplot of finger millet genotypes on five environments using genotype-centered scaling. JR13: Jari 2013, JR14: Jari 2014, KB13: Kobo 2013, SR13: Sirinka 2013, SR14: Sirinka 2014.

genotype absolutely stable and the highest yielder. Thus, genotypes situated closer to the ideal genotype are more desirable (Yan and Tinker, 2006). Accordingly, the local check, Bareda and Gute are more desirable varieties than the others.

Necho has the only advantage of being white as farmers in some areas prefer white seeded varieties to brown seeded types for *injera* making (Assefa et al., 2009). Varieties Necho and Degu were neither stable nor high-yielding. In line with this, Vadivoo et al. (1998) reported that the yield potential of white grained types is generally lower than the brown ones. Besides, as these two varieties are late maturing, they could not fit in the moisture deficit areas like Kobo, Sirinka and Jari.

Based on the overall performance and adaptability of the nine finger millet varieties over the five environments, as evidenced by AMMI and GGE analyses, the bold-seeded variety, Bareda could be recommended for production at Sirinka and Kobo, whereas the local check could still be used at Jari.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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*Full Length Research Paper*

## **Characteristics of three morphotypes of *Solenostemon rotundifolius* [(Poir.) J. K. Morton] based on qualitative morphological traits**

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*Solenostemon rotundifolius* [(Poir.) J. K. Morton] (Lamiaceae) is commonly called Fabirama, Frafra potato or Innala. It is a tuber crop cultivated in many countries in Africa and Asia. Its tubers contain significant rate of carbohydrates, proteins, fibers, vitamins and antioxidants. Besides its nutritional attributes, *S. rotundifolius* has also strong agronomic and economic potentialities and could be financially rewarding to the farm economy. However, *S. rotundifolius* is currently a minor crop in African agro ecosystem. It is a priority to contribute to a better preservation and a sustainable use of its genetic resources. Understanding morphological variability is a key step for *S. rotundifolius* genetic resources management. Previous studies identified three morphotypes based on tuber skin color but a complete description of these morphotypes is not yet done. This study is a contribution to a better description of the main morphotypes of *S. rotundifolius* cultivated in Burkina Faso. Three accessions representing three morphotypes were described based on twenty five qualitative morphological traits assessed at different stages of plant growth. Significant variability between the morphotypes was observed for young plant color, leaves morphology, color and form of inflorescence as well as tuber skin and flesh color. This work provided useful tools for the characterization of *S. rotundifolius* genetic resources.

**Key words:** Frafra potato, neglected crop, diversity, qualitative morphological traits, Burkina Faso.

### **INTRODUCTION**

*Solenostemon rotundifolius* [(Poir.) J. K. Morton] (Lamiaceae), is commonly called Chinese potato, Innala, Hausa potato, Zulu round potato, Sudan potato, Saluga,

Fabirama or Frafra potato. It is believed to have originated from Central or East Africa but spread throughout tropical Africa and into South-east Asia. It is

cultivated as tuber crop in many African countries including Burkina Faso, Ghana, Nigeria, Togo, Mali (in west Africa), Cameroon and Chad (in central Africa) and some parts of South and East Africa (Schippers, 2000; Gouado et al., 2003; Sugri et al., 2013). In Asia, *S. rotundifolius* is reported to be cultivated in Sri Lanka, South India and Java (Jayakody et al., 2005).

*S. rotundifolius* is an annual herbaceous plant, 15 to 30 cm high, with ascending or prostrate stems and thick leaves having aromatic smell (Sugri et al., 2013). It is specially adapted to the Sahelian region of West Africa. Local varieties of *S. rotundifolius* produce many (up to 70/plant) small sized tubers; 3.78 cm long and 1.53 cm width (Nanéma et al., 2009). The potential yield reported in West Africa ranged from 7 to 20 T/ha (Enyiukwu et al., 2014). The tubers contain significant rate of reducing sugar (26 mg/100g), protein (13.6 to 14.6 mg/100g), crude fat (1.2%), crude fiber (1.6%), phosphorus (36 mg/100g), calcium (29 mg/100g), vitamins A and C, respectively 13.6 mg/100g and 10.3 mg/100g, and antioxidants (Anbuselvi and Balamurugan, 2013; Anbuselvi and Priya, 2013). They are commonly consumed as a curry, baked or fried, or cooked (Agyeno et al., 2014).

Besides its nutritional attributes, *S. rotundifolius* holds strong economic potential and could be financially rewarding to the farm economy (Enyiukwu et al., 2014). During the period of availability, the quantity of tubers sold varied from 16 to 32 Kg/day/person in the main markets of Ouagadougou in Burkina Faso. According to the period and the tubers availability, the prices varied from 1.2 to 3 USD/Kg. This important variation of prices (250%) showed the economic potential of frafra potato (Nanéma et al., 2017).

*S. rotundifolius* is a very important food crop which can contribute to improving food security. Besides its agricultural importance, it has ornamental, medicinal, culinary and many other uses (Kwarteng et al., 2017). Therefore, as mentioned by Chivenge et al. (2015) and Mamadalieva et al. (2017), there are many neglected crops that have the potential to contribute to food security but investigation should be done to clearly demonstrate their potentialities and the priorities in term of research on these crops. It is now a consensus that understanding variability within plant genetic resources is one of the key steps for a sustainable use and conservation of its potentialities. Some research activities were already carried out on *S. rotundifolius* germplasm and contributed to identify a set of useful traits that could be used as descriptors for this crop (Opoku-Agyeman et al., 2007;

Nanéma et al., 2009). Some other works focused on the identification of the main morphotypes within *S. rotundifolius* genetic resources based on tuber skin color (Prematilake, 2005; Sugri et al., 2013).

A description based on one trait could lead to some confusions between the morphotypes. The objective of this study is to contribute to a better description of the main morphotypes of *S. rotundifolius* cultivated in Burkina Faso based on a set of qualitative morphological traits. This will give some useful tools for the identification of the morphotypes for research activities on agronomic, economic or nutritional potentialities of *S. rotundifolius*.

## MATERIALS AND METHOD

### Plant material

Three accessions (E02, E35 and E20) representing three morphotypes of *S. rotundifolius* (respectively A, B and C) were used for this study (Table 1). These accessions were identified based on morphological variation observed during our previous research on *S. rotundifolius* genetic resources. The accession E02 was collected in the province of Passoré in the North region of Burkina Faso. The accessions E35 and E20 were collected in the province of Nahouri in the South region of Burkina Faso. For each accession, 30 tubers were randomly selected for the experiment (Table 1).

### Study area and experimental design

The research was carried out in the research farm of the Faculty of Earth and Plant Sciences of the University Ouaga I Joseph KI-ZERBO in Ouagadougou (12°21'56" N; 1°32'01" W). A total rainfall of 665.1 mm was registered during the period of the experiment (July 2016 to January 2017). The experiment was laid out in Fisher blocks with three replications. The replication consisted in three lines of height plastic buckets perforated at the bottom to improve drainage. Each plastic buckets (9 L) contained a mix of sun (1/3) and potting soil (2/3). The spacing was 50 cm between the lines, 40 cm between the plants and 50 cm between the blocks. One tuber was planted per bucket on 25 July 2016. An additional irrigation was bring after the rainy season from October 2016 to January 2017.

### Morphological traits

A total of 25 qualitative morphological traits were assessed at different stages of plant growth. These traits were identified during our previous research activities. The different variants were identified and scored per plant. At all, the morphological traits were observed on 24 plants per morphotype.

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**Table 1.** List of the accessions used for the morphological characterization of the morphotypes of *S. rotundifolius*.

Accession's number	Province of origin	GPS coordinates	Morphotypes
E02	Passoré	12° 58' 00" N 2° 16' 00" W	A
E35	Nahouri	11° 15' N 1° 15' W	B
E20	Nahouri	11° 15' N 1° 15' W	C

Legend: A, B and C are names of the morphotypes of *S. rotundifolius*; E02, E35 and E06 are accessions' numbers in the genes bank of the University Ouaga I Pr Joseph KI-ZERBO (Burkina Faso); GPS: Global Positioning System.

**Table 2.** Morphological traits observed on the morphotypes of *S. rotundifolius*.

Stage	Morphological traits
Young plant	Color of stems (COST) Color of leaves (COL1)
Vegetative growth stage	Foliage color (FCO) Thickness of leaves (TLE) Color of apical leaves (CAL) Variation of leaves color when injured by insects (LCI) Stature of main stem (SMS) Stature of secondary stems (SSS)
Flowering stage	Number of flower buds per cluster (NFB) Color of flower buds (CFB) Type of inflorescence (TIN) Level of branching of inflorescence (LBI) Arrangement of clusters of flowers on the rachis (AFR) Flowers persistence on the rachis (FPE) Color of sepals (COSe) Color of petals (CPE) Color of rachis (CRA) Shape of the section of main stems (SSS) Color of leaves of adult plant (COL2)
After harvesting	Position of tuberous roots (PTR) Tuber shape (TSH) Tuber skin color (TSC) Tuber flesh color (TFC) Presence of lateral tubers (PLT) Texture of tuber skin (TTS)

#### Morphological traits observed at vegetative stage

Height morphological traits were observed during the vegetative stage. The color of stems (COST) and the color of leaves (COL1) of young plant were scored at juvenile stage (Table 2). During

the plant growth, the foliage color (FCO), the thickness of leaves (TLE), and the color of apical leaves (CAL) were observed. The variation of leaves color when injured by insects (LCI), the main stem (SMS) and the secondary stems (SSS) stature were observed before flowering period.

**Table 3.** Variability between morphotypes at juvenile stage.

Morphological traits	Morphotypes		
	A	B	C
Color of stems (COST)	Green	Red	Green
Color of leaves (COL1)	Green	Red	Green

**Figure 1.** Young plant of *S. rotundifolius* presenting green stems (morphotype A).**Figure 2.** Young plant of *S. rotundifolius* presenting green leaves (morphotype A).

#### Morphological traits observed at flowering stage and after harvesting

A total of seventeen morphological traits were observed on the inflorescence, the stems and the tubers after flowering. Nine of them were observed on the inflorescence. These traits were the number of flower buds per cluster (NFB), the color of flower buds (CFB), the type of inflorescence (TIN), the level of branching of inflorescence (LBI), the arrangement of clusters of flowers on the rachis (AFR) and the flowers persistence on the rachis (FPE). The color of sepals (COSe), and the color of petals (CPE) were observed on three randomly selected flowers per plant. The color of rachis (CRA) was also observed. Besides the morphological traits observed on the inflorescence, two were observed on the stems and the leaves. These were the shape of the section of main stems (SSS) and the color of leaves of adult plant (COL2). Six traits were observed on the tubers. After harvesting, the position of tuberous roots (PTR), the tuber shape (TSH), the tuber skin color (TSC), the tuber flesh color (TFC), the presence of lateral tubers (PLT) and the texture of tuber skin (TTS) (Table 2).

#### Data analysis

The individuals with missing data were eliminated. A consensus

value for each morphological trait was identified based on the individual score of each plant. The morphotypes were then described based on the consensus value for all the morphological traits.

## RESULTS

### Variability of the morphotypes at juvenile stage

A variability was observed between young plant of the morphotypes for stems and leaves color (Table 3). The stems and leaves of young plants of morphotypes "A" and "C" were green (Figures 1 and 2) while the young plants of morphotype "B" were red (Figures 3 and 4).

### Variability of the morphotypes at vegetative growth stage

Variability was observed between the morphotypes at vegetative stage (Table 4). The color of foliage was green



**Figure 3.** Young plant of *S. rotundifolius* presenting red stems (morphotype B).



**Figure 4.** Young plant of *S. rotundifolius* presenting reddish leaves (morphotype B).

for morphotype “A”, dark green for morphotypes “B” and light green for morphotype “C”. The color of apical leaves did not vary from the color of whole foliage. No particular color was observed on the leaves when injured by insects. The morphotypes also varied for the level of

leaves thickness. The leaves of the morphotype “A” were very thick while those of the morphotypes “B” and “C” were relatively less thick (Figure 5).

#### Variability of the morphotypes at flowering stage

The morphological traits observed at flowering stage revealed important variability between the morphotypes. The inflorescence was an apical spike. Some inflorescences with primary branching were observed for the morphotypes “A” and “B” (Table 5). The flower buds color was green with reddish pigmentation for the morphotype “B” (Figure 6) but it was green for the morphotypes “A” (Figure 7) and “C” (Figure 8). The number of flower buds per cluster was four for the morphotypes “A” and “C” but it was three for the morphotype “B”. The clusters of flowers were opposite on the rachis for all the morphotypes. The flowers buds and the flowers were no persistent on the rachis. After flowering, the color of rachis was reddish for the morphotype “A” but was green for the morphotypes “B” and “C”. The morphotype “A” developed elongated flowers with green-reddish sepals and white-purple petals (Figure 9). The sepals of the flowers of the morphotype “B” was reddish and the petals were very purple (Figure 10). For the morphotype “C”, the sepals were green and the petals were reddish (Figure 11). The morphological traits observed on the stems and the leaves after flowering did not vary. The section of stems was quadrangular for all the morphotypes and the leaves were dark green.

#### Variability of the morphotypes for the morphology of the tubers

The tuber skin and flesh color, and the tuber shape were the discriminant traits observed on tubers (Table 6). The tubers of the morphotype “A” were black skin (Figure 12) and the flesh color was white (Figure 13). The tubers of the morphotype B, skin color was red (Figure 14) and the tuber flesh color was white-yellow (Figure 15). The tubers of the morphotype “C” skin color was white-yellow (Figure 16) and the flesh color was yellow (Figure 17). Tubers were oblong for morphotypes “A” and ovoid for the morphotypes “B” and “C”. For all the morphotypes, the tuberous roots were observed on the upper parts of the roots. The tubers were rough and some tubers presented lateral tubers.

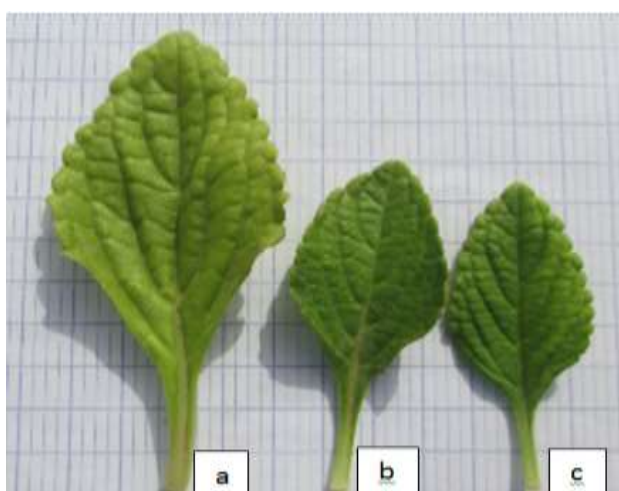
#### DISCUSSION

Three morphotypes of *S. rotundifolius* were described



**Table 4.** Variability between morphotypes at vegetative growth stage.

Morphological traits	Morphotypes		
	A	B	C
Foliage color (FCO)	Green	Dark green	Light green
Color of apical leaves (CAL)	Green	Dark green	Light green
Variation of leaves color when injured by insects (LCI)	No	No	No
Thickness of leaves (TLE)	Strong	Low	Low
Stature of main stem (SMS)	Ascending or prostrate	Ascending or prostrate	Ascending
Stature of secondary stems (SSS)	Prostrate	Prostrate	Prostrate

**Figure 5.** Thickness of leaves of *S. rotundifolius*; a: leaf of morphotype A; b: leaf of morphotype B; c: leaf of morphotype C.

The main stem was ascending or prostrate for the morphotypes "A" and "B" and generally ascending for the morphotype "C". The secondary stems of all the morphotypes were prostrate.

**Table 5.** Variability between morphotypes at flowering stage.

Morphological traits	Morphotypes		
	A	B	C
Type of inflorescence (TIN)	Spike	Spike	Ear
Level of branching of inflorescence (LBI)	Primary branching	Primary branching	No branching
Color of flower buds (CFB)	Green	Green-reddish	Green
Number of flower buds per cluster (NFB)	Four	Three	Four
Arrangement of clusters of flowers on the rachis (AFR)	Opposite	Opposite	Opposite
Flowers persistence on the rachis (FPE)	No persistent	No persistent	No persistent
Color of rachis (CRA)	Purple	Green	Green
Color of sepals (COSe)	Green-reddish	Reddish	Green
Color of petals (CPE)	White-purple	Purple	Reddish
Shape of section of the main stem (SSS)	Quadrangular	Quadrangular	Quadrangular
Color of leaves of adult plant (COL2)	Dark green	Dark green	Dark green



**Figure 6.** Spike of morphotype B of *S. rotundifolius* presenting flower buds; a: flower buds.



**Figure 8.** Spike of morphotype C of *S. rotundifolius* presenting flower buds; a: flower buds.



**Figure 7.** Spike of morphotype A of *S. rotundifolius* presenting flower buds; a: flower buds.



**Figure 9.** Spike of the morphotype A of *S. rotundifolius* showing flowers; a: flower.

based on morphological traits observed on leaves, stems, inflorescences and tubers. At juvenile stage, the presence red coloration on young plant was identified to be the main difference between the morphotypes. The variation

of young plant color was also observed by Nanéma et al. (2009) as a discriminant traits within *S. rotundifolius* genetic resources. According to Price and Sturgess



**Figure 10.** Spike of the morphotype B of *S. rotundifolius* sowing flowers; a: flower.



**Figure 11.** Spike of the morphotype C of *S. rotundifolius* sowing flowers; a: flower.

(1938), the reddish color observed on *Lamiaceae* species are due to the presence of anthocyanins (mainly cyanidine saccharides).

During the vegetative growth stage, the main variation was observed for leaves thickness and the stature of main stem. All the morphotypes produced thick leaves. As suggested by Edison *et al.* (2006), leaves morphology is an important parameter for water regulation in plant tissues. The strong thickness of leaves of the morphotype "A" could be considered as a particular adaptation potential of this morphotype to water scarcity conditions. Besides the leaves morphology, the stature of stems was identified as a discriminant parameter. Previous research activities revealed the presence of pigmentation on *S. rotundifolius* leaves (Agyeno *et al.*, 2014).

The most significant discriminant traits were observed on the inflorescence. These parameters can be sufficient to identify the morphotypes. Our previous works on *S. rotundifolius* variability mentioned the color of the petals of the morphotypes "A" and "B" (Nanéma *et al.*, 2009). This work is the first report on the flowering of the morphotype "C". The other morphological traits observed after flowering did not reveal differences between the morphotypes. It was the stem section, that was quadrangular and the color of leaves that was green. The quadrangular stem section of *S. rotundifolius* was also mentioned by Agyeno *et al.* (2014). However, variability of stem section can be observed within the same morphotype (Nanéma *et al.*, 2009). A pigmentation on leaves was also mentioned at flowering stage. These traits seem to be influenced by *S. rotundifolius* growth conditions.

In addition to the tuber skin color, a variability was observed for tuber flesh color. Current literature mentioned three morphotypes according to the tuber skin color: - the morphotype with white skin tuber; the morphotype with red skin tuber; and the morphotype with black or brown skin tuber (Prematilake, 2005; Nanéma, 2010; Sugri *et al.*, 2013). Chevalier and Perrot (1905) mentioned these morphotypes respectively as varieties "alba", "rubra" and "nigra". These authors suggested the presence of a fourth variety with black skin tuber called "javanicaminum". Some research activities were carried out on *S. rotundifolius* based on the tuber skin color as the main criteria of identification of the varieties (Jayakody *et al.*, 2005; Priya and Anbuselvi, 2013, Taye *et al.*, 2012). After harvest, the tuber skin color is the most accessible criteria for identification of the morphotypes but any error of color appreciation could lead to ambiguous results. Additional morphological traits could be the tuber flesh color and tuber shape.

The tubers of all the morphotypes were rough and glabrous. Other research activities in West Africa also mentioned the lack of hairiness on tubers of *S. rotundifolius* (Opoku-Agyeman *et al.*, 2007; Agyeno *et al.*, 2014).



**Table 6.** Variability of the morphotypes for the morphology of the tubers.

Morphological traits	Morphotypes		
	A	B	C
Position of tuberous roots (PTR)	Upper part of roots	Upper part of roots	Upper part of roots
Tuber skin color (TSC)	Black	Red	White-yellow
Tuber flesh color (TFC)	White	White-yellow	Yellow
Tuber shape (TSH)	Oblong	Ovoid	Ovoid
Presence of lateral tubers (PLT)	Present	Present	Present
Texture of tuber skin (TTS)	Rough	Rough	Rough

**Figure 12.** Black skin color of tubers of the morphotype A.**Figure 15.** White-yellow flesh color of tubers of the morphotype B.**Figure 13.** White flesh color of tubers of the morphotype A.**Figure 14.** Red skin color of tubers of the morphotype B.**Figure 16.** White-yellow skin color of tubers of the morphotype C.

In Asia, some varieties of *S. rotundifolius* produce hairy tubers (Jayakody et al., 2005). This difference could be due to genetic factor or to growth conditions. For all the



**Figure 17.** Yellow flesh color of tubers of the morphotype C.

morphotypes, many branched tubers were identified. *Solenostemon rotundifolius* produced small size tubers and the presence of branched tubers make peeling very difficult. According to Enyiukwu et al. (2014), branched tubers make the crop unattractive and reduce the marketability of the tubers.

The described morphotypes were identified in *S. rotundifolius* germplasm in Burkina Faso. Based on some morphological traits used in previous works, the three morphotypes were reported to be cultivated in West Africa (Sugri et al., 2013; Agyeno et al., 2014). The morphotype “A” and “B” are cultivated in Sri Lanka respectively as “Bola” and “Dik” (Prematilake, 2005, Jayakody et al., 2005). Some research activities highlighted the influence of genetic variability on tuber nutritional, medicinal potentialities and their behavior in conservation (Jayakody et al., 2005; Priya and Anbuselvi, 2013; Parmar et al., 2017; Mamadalieva et al., 2017; Azad et al., 2017). A clear classification of accessions used in future research on *S. rotundifolius* could contribute to a better analysis of the results. This include nutritional, agronomical and economical potentialities as well as genetic diversity.

Future research activities could also be focused on the existence of variability within the morphotypes. Other aspects could be the description of flower morphology. Similar studies already led to the revision of *Borassus* classification (Bayton et al., 2006).

## Conclusion

This study described three morphotypes of *S. rotundifolius* cultivated in Burkina Faso based on a set of qualitative morphological traits. These morphological traits can be used as descriptors for *S. rotundifolius*. It is an important step towards full description of the morphotypes of this important tuber crop. The future studies on morphological

variability could focused on flower structure and microscopic description of plant tissues. A complete description of the morphotypes will provide useful information for a sustainable management of genetic resources of *S. rotundifolius*.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENT

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*Full Length Research Paper*

# Appropriate planting dates and plastic mulch for increasing common tomato varieties yield in South Texas

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In South Texas, most of tomato (*Lycopersicon esculentum* Mill.) crops are produced on plastic mulch due to the elevated temperatures and solar radiations. The study objectives were to; determine the suitable planting dates for increasing tomato varieties production under different planting dates in early spring and late winter, and evaluate the influence of using the plastic mulch (black and white. In the Spring season, nine tomato varieties (four rounds and five roma) were grown. The round varieties were the Torero, Mykonos, Shourouq, and TAM Hot-Ty, and the roma varieties were Prunus, Rio Grande, Seri, DRP-8551, and SV8579TE. The best five varieties from the spring season and two more varieties were selected for evaluation in the fall including; SV8579ET, Mykonos, DRP-8551, TAM-HOT-T4, Shourouq, Tycoon, and Everglade. All the tomato varieties were evaluated during the Spring season under three different planting dates (from late-February till late-March) and three mulching treatments (black, white plastic mulch, and bare soil); and during the fall season during two planting dates (from early to mid-September) and two mulching treatments (black and white plastic mulch). Higher average marketable yields were observed in the spring season than the fall season. The best varieties during the spring season were DRP-8551, SV8579TE, Shourouq, and Seri with yields ranging from 68,630 to 57,237 kg/ha, whereas the best varieties in the fall; were DRP-8551, SV8579TE, and Tycoon with yields ranging from 47,123 to 60,674 kg/ha. In both seasons, white plastic mulch resulted in higher yields compared to the black and bare tomato yields.

**Key words:** Planting dates, plastic mulch, tomato yield.

## INTRODUCTION

Tomato is one of the most important vegetables grown under open field as well as protected structures throughout the world (Singh et al., 2015). High temperature is one of the main limitations to extend the production period throughout the year because it

decreases tomato productivity by reducing flower production and/or fruit set (Hossain et al., 2013). Due to the conditions of high ambient temperature and solar radiation during the spring and summer seasons in South Texas, most of tomato (*Lycopersicon esculentum* Mill.)

crops are produced on plastic mulch of diverse colors. The benefits associated with the use of plastic mulches have been reported in several studies (Liakatas et al., 1986; Lamont, 1993). The color of the mulch has several effects on the phenology of the crop and possibly on the variety of the crop being grown. Black polyethylene plastic mulch is the standard plastic mulch used in vegetable production (Gordon et al., 2010). Researchers indicate that black mulch is recommended during the spring to warm the soil (Hatt et al., 1995; Lamont, 1993). Black plastic mulch increased number of fruit in tomato by five fruits per plant compared to bare ground (Díaz-Pérez and Batal, 2002). Higher yields have also been obtained using clear plastic for many crops such as strawberries (*Fragaria* sp.) (Johnson and Fennimore, 2005). Hatt et al. (1995) and Schalk and Robbins (1987) indicated that in the summer and fall, aluminum or white colored mulches are preferred because these mulches heat the soil less than black mulch. Ashrafuzzaman et al. (2011) also reported that the highest weed dry weight was recorded with the transparent plastic and the lowest with the black plastic. Brown and Brown (1992) reported earlier harvest of tomato in aluminum followed by silver and black mulch, respectively. Therefore, research indicates that crop responses to colored mulches are inconsistent, depending on the season, the year, and the region (Csizinszky et al., 1995). Ham et al. (1993) reported that white-on black and silver mulches reflect 48 and 39% of shortwave radiation, respectively. Also, the results reported by Gordon et al. (2010) indicate that tomatoes in red mulches set fruit earlier and produced more ripe fruit than plants grown in black plastic. In addition to, the use of plastic mulches to increase tomato yield production, the selection of the appropriate planting date could lead to obtaining the maximum yields for some varieties. Crop breeding programs try to develop varieties resistant to heat to extend the tomato production windows and achieve better market opportunities in each region. However, managing the crops by using different varieties, planting dates and plastic colors may also extend the production windows. Planting date is an important factor in crop production that can affect plant maturity, harvest date, yield, and quality. The results reported by (Gent, 1992) showed that a two-week delay in planting resulted in delayed fruit maturity by two weeks for early season HT tomato production. Selecting appropriate planting dates may lead to greater yield and contribute to better vegetable quality (Kleinhenz and Wszelaki, 2003). Rogers and Wszelaki (2012) reported that tomato planted earlier in high tunnels yielded more marketable fruit during the production season than plants established on later planting dates. However, planting dates appropriate for one cultivar may not be suitable for

another and this statement may also be true for different varieties. For some plant species, different planting dates affect vegetative growth but don't affect reproductive growth (Cebert et al., 1990). The objectives of this study were, to determine the suitable planting dates for increasing tomato varieties production under three different planting dates for early spring and two planting dates for the late winter, and to evaluate the influence of the plastic mulch (black and white) on these varieties.

## MATERIALS AND METHODS

Field studies were conducted in the Spring and Fall of 2016 at Texas A&M AgriLife Research and Extension Center, Weslaco, Texas (26.1595° N, 97.9908° W) in Willacy fine sandy loam soil with 0 to 1% slope. Climate conditions were characterized as semi-arid. The mean daily maximum temperature is 45 C° in August while the minimum temperature is 2°C in January. The area receives a mean annual rainfall of 509.8 mm.

### Spring experiments

Three treatments were established in a split plot laid on a randomized complete design with three raised beds covered with black or white plastic mulch and one with bare ground. A set of three raised beds were established, in three different planting dates. Nine tomato varieties, five roma (*Prunus*, Rio Grande, Seri, DRIP-8551, and SV8579TE) and four round (Torero, Mykonos, Shourouq, TAM Hot-Ty) were evaluated. The varieties were selected according to certain factors which include tolerance and resistance to diseases, local heirloom tomato and based on farmer preferences to grow certain varieties in this region. Each plot was replicated three times, and four plants per plot was established. In each plot tomato plants were spaced 0.46 m between plants and 2 m between rows. There was a spacing of 1.2 m between plots and the average plant density was 10,760 plants ha<sup>-1</sup>. The TAM Hot-T4 and SV8579TE varieties were developed by the TAMU program of Dr. Crosby, whereas Seri, Mykonos, Shourouq, and DRP-8551 were developed by Seminis (St. Louis, Missouri, USA). Torero and Prunus were developed by De Ruiters (Monsanto Invest B.V., Amstelveen The Netherlands). Tomato seedlings were planted in 128 cell trays and kept in the greenhouse, and around 90% of the seeds germinated.

### Fall experiments

The same experimental design was followed, however only seven varieties, two planting mulches and two planting dates were evaluated (Table 1). The best five varieties from the spring trial were selected for the fall trial evaluation. In addition, two more varieties suggested by the farmers were selected for the study. The varieties evaluated during the fall were the SV8579ET, Mykonos, DRP-8551, TAM-HOT-T4, Shourouq, and Tycoon which is a commonly grown variety during the fall season in this region, and Everglade, which is a new variety introduced in this region. Only the white and black plastic were evaluated during the fall season

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**Table 1.** Planting and harvest dates established during the two experimental periods (Spring and Fall seasons) in Weslaco, TX.

Planting dates	Harvest dates		
	1 <sup>st</sup> Harvest	2 <sup>nd</sup> Harvest	3 <sup>rd</sup> Harvest
<b>Spring season</b>			
1 <sup>st</sup> (29 February 2016)	19 May 2016	25 May 2016	9 June 2016
2 <sup>nd</sup> (15 March 2016)	30 May 2016	30 May 2016	9 June 2016
3 <sup>rd</sup> (31 March 2016)	14 June 2016	20 June 2016	
<b>Fall season</b>			
1 <sup>st</sup> (6 September 2016)	21 Dec 2016	4 Jan 2017	17 Jan 2017
1 <sup>st</sup> (19 September 2016)	21 Dec 2016	4 Jan 2017	17 Jan 2017

because these were the ones that produced better results in the spring experiment.

The tomato varieties were transplanted to the field six weeks after germination. The tomato transplanting trays were placed outside the greenhouse for acclimatization and hardening two days before transplanting them into the field. Black on white embossed non-degradable plastic mulch with dimensions of 1.8 m x 732 m and 0.032 mm of thickness was used. Prior to the laying of the mulch, beds were raised using a tractor with a rolling cultivator unit, and the drip tape was injected into the soil to a depth of 5 cm. The plastic mulch was placed with the white side facing up. Holes were punctured into the plastic mulch at the correct spacing before transplanting.

In both seasons, the fertilization was applied through irrigation. Different formulated liquid fertilizers were used at various stages of the plant but applying the same amounts to all treatments and replications. Fertilization was applied weekly following common recommendations for South Texas (Dainello and Anciso, 2004). After transplanting, the focus was on developing a good root system so fertilizer with a higher concentration of phosphorus was used, whereas during the foliage development, a fertilizer with high nitrogen was used. Regarding the flowering and fruiting stages micro and macronutrients were added for nutrition of the plants to obtain the best results. Tomato plants were irrigated with a subsurface drip irrigation system for all the treatments during the two growing seasons. The drip tubing has a nominal discharge of 0.75 L h<sup>-1</sup> per emitter and each emitter is spaced every 30 cm (Streamline, Netafim, Riverside, CA 92507). Plants were irrigated the same day they were transplanted. During the growing season, irrigation was applied when a soil moisture sensor (Watermark Soil Moisture Sensor, Irrrometer Co, Riverside, CA 92507) installed at a depth of 30 cm reached 20 cb. One watermark sensor was installed in each bed about 5 cm from the drip line and placed only in one variety (the same variety at different beds). An irrigation depth of approximately 12 mm was applied in each irrigation. Pests such as downy mildew, powdery mildew, whiteflies, thrips, worms and mites, as well as weeds were kept under control with some chemical applications as recommended for the South Texas region (Dainello and Anciso, 2004).

#### Data collection and statistical analysis

Tomato fruits were manually harvested at maturity between 10 to 12 weeks after transplanting and were weighed per plot to estimate the gross yield per each treatment. The marketable yields excluding tomatoes affected with fruit disorders (catface, cracking, puffiness, zippering or affected with diseases) were collected and analyzed statistically using regression mixed model for analysis split plot designs at 5% level of significance.

## RESULTS

### Spring season

During the Spring season, a statistically significant difference was observed by the effect of planting date, plastic color, and variety on tomato yield (Table 2). The planting dates evaluated during the spring season were from February 29 (first planting date) to 31 March 2016 (third planting date). Significant differences were observed among the yield of the three planting dates ( $P=0.0156$ ). The highest average yield was observed for the second planting date (53,20 kg/ha) and a significant decrease in yield was observed during the first and third planting dates with 47,566 and 45,484 kg/ha, respectively. No significant difference was observed between the first and last planting dates (Table 3).

Significant differences on yield were observed between the two plastic treatments and the bare ground soil treatment ( $P < 0.0001$ ). The white plastic resulted in a higher average yield (for all the planting season dates and tomato varieties) with a yield of 70,444 kg/ha followed by the black plastic and bare soil treatments with 45,185 and 30,741 kg/ha respectively (Table 4). A significant difference was observed among the tomato varieties ( $P < 0.0001$ ). Table 5 shows that the highest tomato yields were observed for the SV8579TE (60,234 kg/ha), DRP-8551 (56,481 kg/ha), and Shourouq with 53,427 kg/ha. No significant difference on average yield was observed among these varieties. Similar yields were observed for TAM-Hot-Ty, Seri, Mykonos, and Prunus with an average yield of 50,468 kg/ha. The lowest yields were observed for the Torero and Rio Grande varieties with 35,729 and 31,367 kg/ha respectively.

There was a significant effect of the planting date and the plastic mulch ( $P=0.0017$ ) during the spring season. The highest average tomato yields were obtained using the white plastic during the second and first planting dates with 76,986 and 71,857 kg/ha, respectively (Table 6). The second highest yields were observed for the third planting date using the white plastic with 62,487 kg/ha and second planting date using the black plastic with 54,448 kg/ha. The third highest yields were observed for

**Table 2.** Results of the Analysis of variance for the spring and fall seasons. \* Refers to Significance at P= 0.05.

Source of variance	F Ratio	Prob > F
<b>Spring season</b>		
Planting date	5.9188	0.0156*
Plastic	146.4336	<.0001*
Planting date x Plastic	4.5695	0.0017*
Variety	9.3781	<.0001*
Variety x Plastic	1.2126	0.2648
Variety x Planting date	2.53	0.0018*
Variety x Planting date x Plastic	0.9347	0.5726
<b>Fall season</b>		
Planting date	2.2588	0.2455
Plastic	12.1473	0.0251*
Plastic x Planting date	44.7531	<.0001*
Variety	15.0265	<.0001*
Variety x Plastic	1.9402	0.1008
Variety x Planting date	0.2751	0.9456
Variety x Planting date x Plastic	4.1715	0.0028*

**Table 3.** Average yields of the tomatoes varieties for three planting dates during the Spring season. ± Represents the standard error. Planting dates not connected with same letters, are significantly different at P=0.005.

Planting dates	Yield (kg/ha)
2nd planting                    A	53,320 ± 1633
1st planting                    B	47,567 ± 1633
3rd planting                    B	45,484 ± 1633

**Table 4.** Average yields of tomato varieties using the white and black plastic, and bare soil during the spring season (the three planting dates), and the white and black plastic during the fall season (the two planting dates). ± Represents the standard error. Treatments not connected by same letters are significantly different at P= 0.05.

Treatments	Yield (kg/ha)
<b>Spring season</b>	
White                    A	70,444± 1,627
Black                    B	45,185± 1,626
Bare                    C	30,741± 1,629
<b>Fall season</b>	
White                    A	41,413± 4200
Black                    B	23,811± 4198

the first and third planting dates using the black plastic and the third planting date of the bare soil with 42,161, 38,947, and 35,016 kg/ha, respectively. The lowest treatments were observed for the first and second planting dates using bare soil with 28,681 and 28,525

kg/ha, respectively. The highest yields were generally observed in the first two planting dates using the white and black plastics and the opposite was observed for the bare soil, in which the last planting date resulted in higher yields.



**Table 5.** Average yield for each tomato variety under the three treatments and three planting dates during the spring season, and the two-plastic mulch in two planting dates during the fall season.  $\pm$  Represents the standard error. Varieties not connected by same letters are significantly different at  $P=0.05$ .

Varieties		Yield (kg/ha)	
<b>Spring season</b>			
SV8579TE	A		60234 $\pm$ 3020
DRP-8551	A	B	56481 $\pm$ 3022
Shourouq	A	B	53427 $\pm$ 3024
TAM Hot-ty		B	51651 $\pm$ 3021
Seri		B	51101 $\pm$ 3032
Mykonos		B	50788 $\pm$ 3048
Prunus		B	48333 $\pm$ 3024
Torero		C	35729 $\pm$ 3031
Rio Grande		C	31367 $\pm$ 3011
<b>Fall season</b>			
Varieties		Yield (kg/ha)	
Tycoon	A		59,164 $\pm$ 4551
SV8579TE	A		58,602 $\pm$ 4629
DRP-8551		B	47,252 $\pm$ 4537
Mykonos		C	32,565 $\pm$ 4583
Everglade			C D 31,819 $\pm$ 4617
Shourouq			C D 29,284 $\pm$ 4508
TAM-HOT-ty			D 21,292 $\pm$ 4597

**Table 6.** Average tomato yields for the combination between planting dates and treatments during the spring and fall season.  $\pm$  Represents the standard error. Combinations not connected by same letters, are significantly different at  $P=0.05$ .

Planting dates x treatments		Yield (kg/ha)	
<b>Spring season</b>			
2nd planting,White	A		76,986 $\pm$ 2943
1st planting,White	A		71,857 $\pm$ 2943
3rd planting,White		B	62,489 $\pm$ 2943
2nd planting,Black		B	54,448 $\pm$ 2938
1st planting,Black			C 42,161 $\pm$ 2938
3rd planting,Black			C 38,947 $\pm$ 2938
3rd planting,Bare			C D 35,016 $\pm$ 2940
1st planting,Bare			D 28,681 $\pm$ 2940
2nd planting,Bare			D 28,525 $\pm$ 2940
<b>Fall season</b>			
White,2nd planting	A		59,603 $\pm$ 4543
White,1st planting		B	41,979 $\pm$ 4536
Black,1st planting		B	40,568 $\pm$ 4543
Black,2nd planting			C 17,838 $\pm$ 4543

There was significant effect of planting date on the tomato variety yield ( $P=0.0018$ ). Table 7 shows that the highest tomato yields were observed for the DRP-8551 variety-first planting date and SV8597TE- second

planting date, with 68,555 kg/ha. The average yields of the tomato varieties TAM-HOT-Ty- second planting, SV8579TE-first planting, Shourouq-second planting, Shourouq-first planting, Prunus-second planting, Seri-



**Table 7.** Average tomato yields for the combinations among the plastic mulch treatments, three planting dates, and varieties during the spring season.  $\pm$  Represents the standard error. Combinations not connected by same letters are significantly different at  $P=0.05$ .

Varieties x Planting dates																		Yield (Kg/ha)
DRP-8551,1 <sup>st</sup> planting	A																	68,630± 5257
SV8579TE,2 <sup>nd</sup> planting	A																	68,480± 5253
TAM Hot-ty,2 <sup>nd</sup> planting	A	B																64,769± 5255
SV8579TE,1 <sup>st</sup> planting	A	B	C															59,729± 5253
Shourouq,2 <sup>nd</sup> planting	A	B	C	D														58,677± 5261
Shourouq,1 <sup>st</sup> planting	A	B	C	D	E													58,147± 5261
Prunus,2 <sup>nd</sup> planting	A	B	C	D	E													57,382± 5261
Seri,1 <sup>st</sup> planting	A	B	C	D	E													57,237± 5273
Mykonos,2 <sup>nd</sup> planting	A	B	C	D	E													55,892± 5300
Prunus,3 <sup>rd</sup> planting	A	B	C	D	E	F												54,062± 5261
DRP-8551,3 <sup>rd</sup> planting		B	C	D	E	F												53,438± 5257
SV8579TE,3 <sup>rd</sup> planting		B	C	D	E	F												52,491± 5253
Mykonos,3 <sup>rd</sup> planting		B	C	D	E	F	G											51,034± 5300
TAM Hot-ty,3 <sup>rd</sup> planting		B	C	D	E	F	G											50,496± 5255
Seri,2 <sup>nd</sup> planting			C	D	E	F	G											49,715± 5273
DRP-8551,2 <sup>nd</sup> planting			C	D	E	F	G	H										47,376± 5257
Seri,3 <sup>rd</sup> planting			C	D	E	F	G	H										46,351± 5273
Mykonos,1 <sup>st</sup> planting			C	D	E	F	G	H	I									45,439± 5300
Torero,2 <sup>nd</sup> planting				D	E	F	G	H	I	J								44,008± 5272
Shourouq,3 <sup>rd</sup> planting					E	F	G	H	I	J								43,456± 5261
TAM Hot-ty,1 <sup>st</sup> planting						F	G	H	I	J	K							39,687± 5255
Torero,1 <sup>st</sup> planting							G	H	I	J	K							36,243± 5272
Rio Grande,2 <sup>nd</sup> planting								H	I	J	K							33,581± 5238
Prunus,1 <sup>st</sup> planting								H	I	J	K							33,556± 5261
Rio Grande,3 <sup>rd</sup> planting									I	J	K							31,090± 5238
Rio Grande,1 <sup>st</sup> planting										J	K							29,429± 5238
Torero,3 <sup>rd</sup> planting											K							26,935±5272

first planting, Mykonos-second planting, and prunus-third planting varieties were not significantly different, and their yields ranged from (64,769 to 54,062 kg/ha). Similar yields were recorded for the DRP8551- Third planting date, SV8579TE-third planting, Mykonos-third planting and TAM-HOT-Ty-third planting with no significant differences and yields ranging from 53,438 to 50,496 kg/ha. The lowest yields (below 36,243 kg/ha) were observed for Rio Grande-first, second, and third planting dates, prunus-first planting date and torero-third planting date. Whereas, there was no effect of the plastic mulch on the tomato varieties ( $P= 0.2648$ ).

### Fall season

During the fall season, only the white and black plastic were evaluated since they produced the highest yields during the spring season. The white plastic mulch resulted in higher tomato yield (41,413 kg/ha) than the black plastic (23,811 kg/ha) during the two planting dates of the fall season (Table 4).

A highly significant effect of the plastic mulch and planting date combination ( $P=0.0001$ ) was observed on tomato yield (Table 2). The highest yield was observed for the white plastic-second planting date with 59,603 kg/ha, followed by the white plastic-first planting date with 41,979 kg/ha and black plastic-first planting date with 40,568 kg/ha. The lowest yield was observed for the black plastic-second planting with 17,838 kg/ha (Table 6). During the fall season, only seven varieties were evaluated. The Torero and the Rio Grande varieties were not included in the fall study because of the low yield attained during the spring season. The tomato yields of the different varieties were statistically different ( $P=<0.0001$ ), (Table 2). The highest yields were observed for the Tycoon and SV8579TE with 58,883 kg/ha, followed by the DRP8551 with 47252 kg/ha. The next lower yields were observed for Mykonos, Everglade, and Shourouq with 32,565, 31,819, and 29,284 kg/ha, respectively. The lowest yield was observed for the TAM-HOT-Ty variety with 21,292 kg/ha (Table 5).

A non-significant effect was observed of the planting date on the variety. However, a significant effect of the

**Table 8.** Average tomato yields for the combinations among the plastic mulch treatments, two planting dates, and varieties during the fall season. ± Represents the standard error. Combinations not connected by same letters are significantly different at P=0.05.

Variety x Planting date x Plastic mulch											Yield (kg/ha)
Tycoon,2 <sup>nd</sup> planting, White	A										97,632± 8516
DRP-8551,2 <sup>nd</sup> planting, White	A		B								79,332± 8141
SV859TE,2 <sup>nd</sup> planting, White			B								74,563± 8675
Tycoon,1 <sup>st</sup> planting, Black			B		C						68,565± 8313
SV859TE,1 <sup>st</sup> planting, Black			B		C		D				65,723± 8565
Tycoon,1 <sup>st</sup> planting, White					C		D		E		52,783± 8143
SV859TE,1 <sup>st</sup> planting, White					C		D		E F		48,937± 8598
DRP-8551,1 <sup>st</sup> planting, Black					C		D		E F		48,160± 8386
Shourouq,1 <sup>st</sup> planting, White					C		D		E F		48,036± 8095
Everglade,2 <sup>nd</sup> planting, White					C		D		E F		46,986± 8623
DRP-8551,1 <sup>st</sup> planting, White					C		D		E F G		46,301± 8386
Mykonos,2 <sup>nd</sup> planting, White					C		D		E F G		45,489± 8657
SV859TE,2 <sup>nd</sup> planting, Black					D		E		F H		45,185± 8672
Shourouq,2 <sup>nd</sup> planting, White					D		E		F G H I		41,604± 8555
Mykonos,1 <sup>st</sup> planting, White							E		F G H I		40,162±8598
Everglade,1 <sup>st</sup> planting, White							E		F G H I J		36,858± 8626
TAM-HOT-Ty,2 <sup>nd</sup> planting, White							E		F G H I J K L		31,614± 8597
Everglade,1 <sup>st</sup> planting, Black							E		F G H I J K		31,083± 8652
Mykonos,1 <sup>st</sup> planting, Black							F		G H I J K L		28,050± 8476
TAM-HOT-Ty,1 <sup>st</sup> planting, Black							G		I J K L		21,864± 8532
TAM-HOT-Ty,1 <sup>st</sup> planting, White							H		I J K L		20,773± 8526
Shourouq,1 <sup>st</sup> planting, Black									I J K L		20,532± 8590
Tycoon,2 <sup>nd</sup> planting, Black									I J K L		17,678± 8666
Mykonos,2 <sup>nd</sup> planting, Black									I J K L		16,559± 8567
DRP-8551,2 <sup>nd</sup> planting, Black									J K L		15,214± 8546
Everglade,2 <sup>nd</sup> planting, Black									K L		12,348± 8141
TAM-HOT-Ty,2 <sup>nd</sup> planting, Black									K L		10,916± 8498
Shourouq,2 <sup>nd</sup> planting, Black									L		69,63± 8498

plastic, under the two planting dates was observed for the tomato varieties (P=0.0028). The highest yields were observed for the Tycoon-second planting date-white (97,632 kg/ha) and DRP8551-second planting date-white plastic with 79,332 kg/ha. No significant differences were observed between the DRP-8551-second planting date-white and the SV89TE-second planting-white, Tycoon-first planting date-black, SV8579TE-first planting date-black with 74,564, 68,565, and 65,723 kg/ha, respectively. The lowest yields (below 16,000 kg/ha) were observed for DRP-8551-second planting-black, Everglade-second planting date-black, TAM-HOT-Ty-second planting-black, and Shourouq-second planting, black (Table 8).

**DISCUSSION**

Planting date is a crucial factor in specialty crop productions (Zhao et al., 2014), because it has exhibited marked influence on the yield of tomato fruits (Singh et

al., 2015). The main objectives of the study were to evaluate the effect of different planting dates on the yield of the tomato varieties and study the tomatoes varieties grown under plastic mulch (white and black) and bare soil (open field). The results of the present study showed that the planting date and plastic mulch exhibit marked influence on the tomato varieties yield during both Spring and Fall season. In the Spring season, nine of the most common varieties grown in South Texas were selected, four round and five roma. The round varieties were the Torero, Mykonos, Shourouq, and TAM Hot-Ty, and the roma varieties were Prunus, Rio Grande, Seri, DRP-8551, and SV8579TE. These varieties were evaluated under three different planting dates during the Spring season (from late-February till late-March) and two different planting dates during the fall season (from early to mid-September). During the spring season, the second planting date resulted in an increase of 57.5 and 78.4% higher average yield than the first and third planting dates, respectively. This average yield increase could be attributed to the optimum temperature for optimum

tomato vegetative growth and yield. Maximum and minimum temperatures recorded during second planting cycle ranged from 20.9 to 31.1°C. Dhaliwal et al. (2017) reported that optimum growth and fruit setting tomato requires from 25 to 30°C day and 15 to 20°C night air temperature. They mentioned that below these optimal temperatures the tomato crop (*Solanum lycopersicum* L.) results in delayed fruiting and decreased fruit yield under field conditions. Equivalent results were observed by Hossain (2004) in Bangladesh, who obtained the highest tomato yield (86.40 t/ha) at early planting (October 25) where the temperatures were favorable for flower initiation and the lowest yields (16.8 t/ha) as planting was delayed possibly because of higher temperatures during the growing season when tomato was planted beyond February 24.

Hamma et al. (2012) in Nigeria observed that an earlier planting date (August, 1-20) performed better in terms of growth because the crop gets enough duration to complete the vegetative phase fully, indicating the importance of exploring the best planting dates in different climates and regions. For example, Ahammad et al. (2009) mentioned that in Bangladesh the tomato yields can be reduced from 48.7 t/ha if planted in Dec 1 to 7.2 t/ha if planted later than February 1. Although they mentioned that planting temperatures affect growth they did not mention what temperatures they observed during the growing season. However, this research points out the importance of determining the optimum window of opportunity for planting in different regions.

Significant difference of the yield among varieties were observed in each planting date. The best varieties during the spring season were DRP-8551, SV8597TE, Shourouq, and Seri first planting date with yields ranging from 68,630 to 57,237 kg/ha; followed by SV8597TE, TAM-HOT-Ty, Shourouq, Prunus, and Mykonos-second planting date with yields ranging from 68,480 to 55,892 kg/ha; and prunus-third planting with an average yield of 54,062 kg/ha. The variation of the yield of the same varieties in the three planting dates, could be attributed to the weather effects on early maturity.

The tomato yield obtained during the fall season planting dates (from September 6 to 19) resulted in significant lower tomato yields than the Spring season (planted from February 29 to March 31). The yield decrease could be explained by the infection with the white fly and some other common diseases such as early blight caused by *Phytophthora infestans* that strongly affects the late tomato plantations in the South Texas region. Therefore, many of the varieties require specific planting dates to avoid the diseases which probably results in low yield due to low disease resistance. Moreover, in the fall season a yield increase of 25.5% was observed in the first planting date compared to the second planting date. In the fall, the best varieties were DRP-8551, SV8597TE; and Tycoon in the first and second planting dates with yields ranging from 47,123 to 60,674 kg/ha.

Plastic mulches are used extensively in commercial vegetable production (Lamont, 1993). The benefits associated with the use of plastic mulches have been reported in several studies. The most popular plastic mulch worldwide is black, though white-on-black and clear, mulches are also used (Schales, 1990). In the present study, two plastic mulch (black and white) were tested. Plastic mulch affected significantly the tomato yield. The study results revealed that the performance of tomato varieties under black and white plastic mulch was considerably higher than the one grown in bare soil during the spring season. White plastic resulted in 25.3% higher yields than the black plastic, and 39.7% higher than the bare soil in the spring season. Whereas, during the fall season the white plastic resulted in 17.6% higher yield than the black plastic. White plastic can keep adequate temperature and soil moisture in the tomato varieties, as well as preventing the infection of common insects and viruses in the area. In addition, white plastic mulch usually gives cooler temperature than the black plastic because this mulch heats the soil less than the black mulch (Hatt et al., 1995; Schalk and Robbins, 1987). In this study, black plastic resulted in a significant increase of yields (approximately 14.4%) compared to bare soil planted tomatoes. Black plastic mulch is the standard plastic mulch used in vegetable production (Gordon et al., 2010). Moreover, researchers using black plastic instead of bare soil have recorded higher yields (Rajablarjani et al., 2012) and earliness in tomato production (Ibarra et al., 2001; Lamont, 1993). Black plastic also increased number of fruit in tomato by five fruits per plant compared to bare ground grown tomatoes (Díaz-Pérez and Batal, 2002). The low yield obtained in bare soil treatments with no mulch is attributed to the uncontrolled environmental conditions rather than plastic mulch. During the Spring season, there was no significant interaction between the plastic mulch and varieties under the three planting dates due to optimal temperatures for all varieties. However, during the fall season, a major influence of the plastic mulch was observed on the tomato varieties in the two planting dates that can be attributed to the low temperatures of the fall season and the importance of the plastic mulch to make a more suitable environment for tomato growth. The varieties that performed better during the fall season were (Tycoon-second planting) and (DRP-8551-second planting) under white plastic and under black plastic mulch were (Tycoon-first planting), (SV8579TE- first planting), and (DRP-8551-first planting) indicating that during the fall season some varieties performed better under the plastic mulch than the spring season. For example, the DRP-8551 increased yield in the fall season by approximately 50% compared to the spring.

## Conclusion

The present study has demonstrated the effect of

different planting dates and plastic mulch covers (black and white) on the tomato yield. Tomatoes grown under white plastic mulch resulted in approximately 40% increase in the tomato yields than the black plastic mulch and bare soil. Planting the TAM Hot-Ty, SV8597TE, and DRP-8551 in early Spring under white plastic mulch, resulted in higher tomato yields. Whereas, some other varieties resulted in higher yields during late planting dates such as Tycoon in the fall. The production yield is depending on the varieties and its maturity type. Thus, we recommend the use of white plastic mulch to increase the yield as well as the proper selection of the variety. Information given by this study could be useful to growers striving to enhance marketable yields of tomato in south Texas and extend the market windows. During the fall farmers do not want to plant too early to avoid the high environmental temperatures which affect the affect tomato vegetative growth, but they don't want to plant too late to avoid the low temperatures that cause diseases. Farmers could select varieties that are more resistant to diseases, which can be planted earlier or select the plastic that helps the varieties to produce higher yields in late plantings.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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