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Research Article

Water use Efficiency with Interaction of Plants Nutrients Usage

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Abstract

Plant Nutrient Role and Requirement: Plants like other organisms require "FOOD" for their living and growth development. From chemical elements drawn from soil, water, and air, plants build a vast array of plant products.

Plan for Agricultural Water Management: Alleviation and reduction of poverty amongst people in mainly rural areas, and rehabilitation, protection and reclamation of water works and water resources.

Materials and Methods: Cow peas (Vigna Unguiculata), (*Vigna subterranean* – bambara groundnut, Groundnuts (Arachis hypogaea L.), Black gram (Vigna mungo (L.) Hepper) and Mungbeans (Vigna radiate (L.) Wilzcek). Field trial lay out plan (Randomized Complete Block Design), plant sampling and processing (10 plants per plot size), measurement of $^{13}C/^{12}C$ isotopic ratio (Lab instrument; Spectrometry) and statistical analysis Statistica 10.1 (StatSoftInc., Tulsa, OK, USA).

Results: Although there are several reports on symbiotic (N) performance of cowpea, Bambara groundnut, groundnut and mungbean, studies on their C accumulation, shoot C/N ratio, and shoot-water-use efficiency are few. Therefore, evaluation of these parameters in the test grain legumes widely cultivated in South African smallholder sector it was an objectives of the current study where groundnut exhibited high WUE compared to the other grain legumes planted for testing.

Discussion: The aim of this study was therefore to determine the C accumulation and WUE of five grain legumes using C isotopic discrimination ($^{13}C/^{12}C$) values during the 2011/2012 cropping season. South Africa is a semi-arid country with an annual average rainfall < 500 mm in two-thirds of its land mass.

Conclusion: Shoot-biomass (g.plant^{-1}) was high to Bambara-groundnut, C concentration (%) was also high to both Bambara-groundnut and groundnut, C content (g.plant^{-1}) was higher to Bambara-groundnut, $\sum^{13}C$ (‰) was high to groundnut and Bambara-groundnut while the C:N ratio of mung-bean was highest in the study. Therefore WUE reveal that groundnut and Bambara-groundnut are the best users of water whereas other legumes utilize water inefficient compared to the two legumes.

Introduction

Plant Nutrient Role and Requirement

Plants like other organisms require "FOOD" for their living and growth development. From chemical elements drawn from soil, water, and air, plants build a vast array of plant products. These essential elements are plant nutrients. The elements carbon, hydrogen, and nitrogen are derived from the air and water. (T. Nagur, *et al*., 1992) [40]. Africa is a drought – prone continent, making farming risky for millions of small – scale farmers who rely on rainfall to grow their crops. This project aims to develop new drought – tolerant legumes varieties that are well adapted to African agro – ecologies. Considerable work has been done to develop potentially viable products and this project is at an advanced product development stage preparing for field tests under controlled conditions AATF.,2002 [1].

People involved in irrigated agriculture, comprise a diverse group of subsistence, emerging and commercial farmers, and permanent and seasonal labourers and their dependants. The most important methods of irrigation being used are flood irrigation on 28.5% of the total area, sprinkler irrigation on 53% of the area and micro – irrigation on 18.5% of the area. Water is applied for the production of a wide range of field, industrial, horticulture, pasture and forage crops (Piet Odendaal.,2000) [33]. Recent scientific data confirms that nitrate enhances water use efficiency and protects the plant against harsh heat and cold stress (H. J. van Vuuren.,2012) [13] According to the Strategic Research Plan for Agricultural Water Management, the point of departure of applied research is the real – life problems experienced by users of water for livestock watering, rainfed agriculture, irrigation and aquaculture. Overall objectives are increased household food security and farming profitability, as well as efficient growth and equitable distribution of wealth on a regional – economic and macro – economic level. The most important goals to be achieved over the medium – term are:

- Increased technical, biological and economical efficiency of water use,
- Alleviation and reduction of poverty amongst people in mainly rural areas, and
- Rehabilitation, protection and reclamation of water works and water resources.

These goals must be achieved through the creation of knowledge by means of research and influencing the decisions and actions of stakeholders through training and extension (Piet Odendaal., 2000) [33]. The major objectives of molecular breeding at ICRISAT ARE (a) improving drought tolerance, (b) enhancing nutrient-use efficiency, (c) improving quality traits, (d) pyramiding disease and pest resistance genes, (e) assisting introgression breeding, and (f) enhancing hybrid seed production systems. In groundnut, mapping studies currently focus on resistance to foliar diseases but will subsequently be extended to drought tolerance and seed quality (Rodomiro Ortiz., 2000) [37].

The focus areas for research are mainly rural sociology, resource economics, engineering, climatology, hydrology, soil and crops. The emphasis in the research is first and foremost to enhance the management capacity of agricultural water users. Needs – driven, problem – solving research also requires a balance between addressing issues of immediate concern and anticipating issues, which are expected to be of concern in the future. To achieve this, existing channels of communication with representatives of the farming communities, and with researchers themselves, are used to promote co-operation and co-ordination of research (Piet Odendaal.,2000) [33].

Materials and Methods

Selected Cultivars for Planting: Cow Peeas (Vigna Unguiculata) This season was highlighted with the planting of the cow pea variety (cv. Pan 311), out of the Lowveld Research Unit programme. This variety reacts both as an erect type for seed production (late planting) or as prostate (early planting). It has the added advantage of apparently being resistant to virus infection.

Bambara-Food for Africa (*Vigna subterranean* – bambara groundnut)—The beans are related to cowpeas and botanically known as *Vigna subterranean (L) Verdc.* There are two botanical varieties namely *V*. subterranean var. spontanea which includes the wild varieties and *V*. subterranean var. subterranean which includes the cultivated varieties which was highlighted by Bambara groundnut (cv. MB 51(Brian Beck)) during the planting season of the experimental field trial (Literature Citation: (National Department of Agriculture ARC –Grain Crops Institute., Dr C. J. Swanevelder.,1998., ISBN 1-86871 – 022-X [39].

Groundnuts (Arachis hypogaea L.) Substantial evidence exists to show that groundnuts respond to additional fertilizer applications, even though this is not imperative. Groundnuts are adapted to a soil with a pH (H_2O) of 5.3 or higher. If however, the pH is higher than 5.3 to 8.0 certain elements become unavailable, e. g .iron and zinc. Being a leguminous crop, groundnuts can fix atmospheric nitrogen (N) with the aid of root bacteria. For this reason this crop is not dependent on nitrogen fertilization. Root nodules which fix nitrogen effectively have a pink colour when dissected. Groundnuts with effective root bacteria do not need additional nitrogen. The experimental field trial was planted with groundnut (cv.JL24). (Literature Citation: Directorate Agricultural Information Services, Department of

Agriculture., ARC – Grain Crops Institute., Groundnut Production., 2002 [6].

Black Gram (Vigna mungo (L.) Hepper) that is where local market seed was utilized as a new crop under research consideration used. There is no record of black gram production in South Africa, at both commercial and smallholder levels. This crop is however largely produced and consumed in India (Shetty *et al*.,2013).

Mungbeans (Vigna radiate (L.) Wilzcek) That season was highlighted with the planting of the Mungbean variety (cv. CV1973). This study reports an investigation of the effect of black and green grams (Vigna mungo and Vigna radiate respectively), commonly called mungbeans, on the supply of atmospheric nitrogen for a subsequently maize crop (JK Leslie, April 1980).

Field Trial Lay out Plan

A field experiment was carried out in the 2011/2012 summer cropping season at the Lowveld Research Station in Mpumalanga. RCBD is the method used to lay down the trial plan.

Plant sampling and processing

Shoot samples of the five grain legumes were collected from each plot at the flowering stage. The shoots were oven-dried at 70°C for 72 h, weighed, and ground to fine powder using Hammer mill, (Wirsam Scientific and Precision Equipment Pty Ltd, Johannesburg, South Africa). The powder (0.85 mm) was used for ^{13}C isotope analysis by mass spectrometry.

Measurement of $^{13}C/^{12}C$ isotopic ratio

The concentration of C (%C) and $^{13}C/^{12}C$ isotopic ratios of selected legumes and reference plant species were analyzed using a Carlo Erba NA1500 elemental analyzer (Fisons Instruments SpA, Strada, Rivoltana, Italy) coupled to a Finan MAT252 mass spectrometer (Finnigan, MAT CombH, Bremen, Germany) via a Conflo II open-split device, as described for ^{15}N in Chapter 2.

Statistical analysis

All data collected were subjected to a One-way analysis of variance (ANOVA) using Statistica-10.1 (StatSoft Inc., Tulsa, OK, USA). Analysis were done for shoot N concentration, N content, shoot C/N ratio and shoot $\delta^{13}C$, all compared between the test grain legumes. Where mean values showed differences that were significant, the Duncan's Multiple Range Test was used to separate the means at $p \leq 0.05$. Pearson's correlation was carried out to determine the relationship between the variables evaluated.

Results

Basically, during photosynthesis, the CO_2 fixation process in plants involves discriminates of the heavier isotope of C, that is, $^{13}CO_2$, in favour of the lighter isotope of carbon, namely $^{12}CO_2$. The ratio of $^{12}CO_2/^{13}CO_2$ or $^{12}C/^{13}C$, calculated as $\delta^{13}C$ or ^{13}C in organs of C3 plants is used to indicate water-use efficiency. Among other techniques, the water-use efficiency of C3 plants is determined through the use of the isotopes of carbon ($^{13}C/^{12}C$) in dried shoots among other techniques. There is a need to select crops particular that cultivated by smallholder farmers which can tolerate drought because South Africa has had high temperatures, and evapotranspiration coupled with reduced and scanty rainfall (Adisa *et al*., 2017; Elum et al., 2017) [10]. Unfortunately, low-input smallholder farmers hardly afford irrigation infrastructure and their plight is made worse by the scarcity of water in South Africa with groundwater constrained by underlying hard rock formations, and the 37 to 42% loss of potable water through leaks, wastage and illegal connections (National water security, www.gov.za, 2017) [4] .

Basically, the composition of the C isotopes is compared to that in the air to reveal water-use efficiency of the test plant species during its growth period. Calculated as $\delta^{13}C$, the water-use efficiency provides information on the ability of C3 plants to balance the process of acquiring carbon through the process of photosynthesis in relation to the water that get lost in the process (Condon *et al.,*

2004) [5]. It therefore is an important measure of plant and environmental parameters that influence photosynthetic gas exchange processes over time that CO_2 is fixed (Grossnickle *et al.,* 2005) [12]. Furthermore, it provides useful knowledge on the ability of crops to withstand periodic drought during the growth season, making the technique useful in selecting agricultural crops for drought tolerance (Monneveux *et al.,* 2006) [30]. In general, C concentration determined in legume plants typically ranged up to 30% (Sprent et al., 1996), however, there are instances where the C concentration in legume tissue organs is greater than 40% (Post *et al.,* 2007) [7].

With regards to grain legumes such as cowpea, Bambara groundnut, groundnut, mungbean and black gram, quality residues include that which have a C/N ratio that is < 24 g g^{-1} (Hobbie, 1992) [16]. Intriguingly, at times, higher C/N ratio can play a crucial role through protecting soils and maintaining soil water (Rosolem *et al*., 2017). Although there are several reports on symbiotic (N) performance of cowpea, Bambara groundnut, groundnut and mungbean, studies on their C accumulation, shoot C/N ratio, and shoot-water-use efficiency are few. Therefore, evaluation of these parameters in the test grain legumes widely cultivated in South African smallholder sector is an objectives of the current study.

Variation in Growth, C Concentration and Content of Bambara Groundnut, Blackgram, Cowpea, Groundnut and Mungbean at Nelspruit

Water-use Efficiency (WUE) is defined as the amount of biomass or yield accumulated per unit of water used (Paussioura, 1986; Condon *et al.,* 2004) [5]. Shoot $\delta^{13}C$ isotopic discrimination has been used to determine WUE as well as identify species or genotypes with greater WUE (Farquhar *et al.,* 1989; Basu *et al*., 2003) [38]. In this study, shoot $\delta^{13}C$ values ranged from −27.31‰ in mungbean to −26.08‰ in groundnut, indicating significant differences in WUE between the grain legume species. The ^{13}C discrimination values obtained in this study are similar to those reported elsewhere (Mokobane 2013; Zwane, 2014) [25]. This study showed a highly significant correlation between $\delta^{13}C$ discrimination and shoot biomass as well as pod yield (Figures 3.5, 3.6 and 3.10). However, some studies have found strong but negative correlations between $\delta^{13}C$ (or WUE) and grain or biomass yield (Morgan *et al*., 1986; Ebdon, Petrovic and Dawson, 1998; Kumar *et al*., 2011; Zhang *et al*., 2015) [42]. Paussioura (1986) has explained that high plant biomass production is strongly associated with WUE. According to Austin *et al*. (1990), the relationship between ^{13}C isotopic discrimination and biomass or grain yield could be positive or non-significant depending on the soil moisture status. Canavar *et al.* (2014) also showed that under drought stress the relationship between WUE and ^{13}C isotope was negative, and no significant relationship was evident under well-watered conditions. However, Kumar *et al*. (2011) [26] found positive relationships between $\delta^{13}C$, biomass / grain yield and N_2 fixation, but argued that the relationship between $\delta^{13}C$ and biomass / grain yield could vary depending on the plant growth stage (vegetative or mature) at which samples were collected. In this study, Bambara groundnut and groundnut which showed relatively greater $\delta^{13}C$ values of -26.44 and -26.08, respectively, contributed the highest N to the cropping system, while the species with the least $\delta^{13}C$, made the lowest N contribution (Figures 3.9, 3.10, 3.11). This can be interpreted to mean that there is a functional relationship between plant WUE and symbiotic N_2 fixation.

Taken together, these results suggest the existence of a functional relationship between N_2 fixation and photosynthesis as well as symbiotic N nutrition and plant WUE of organs such as shoots and pods of grain legumes grown under rain-fed conditions. These findings are useful for selecting legume species with better WUE and greater tolerance to drought, especially in a changing climate.

Figure 3.1 is showing plant growth of the selected five grain legumes. Briefly, there were significantly differences in plant growth between the grain legumes with Bambara groundnut with the largest growth, followed by groundnut, intermediate in cowpea and blackgram, and least in mungbean. Of the test legumes, shoot C concentration was significantly higher in groundnut and in Bambara groundnut (Figure 3.2), species which also had higher shoot dry weight at Nelspruit. Intermediate C concentration was shown by blackgram whilst least was revealed by cowpea and mungbean (Figure 3.2). It is interesting to note that mungbean also had the lowest shoot dry weight. As to be expected, Bambara groundnut, which showed the highest shoot dry weight, accumulated the most C content (Figure 3.3). The second-highest C content was exhibited by groundnut and intermediate was shown by cowpea. For example, high %C values (40 - 49) have been reported in Bambara groundnut collected from farmers' fields in the Mpumalanga Province (Mohale *et al.*, 2014) [18]. According to Post *et al.* (2007) [34], such high values indicate high lipid distribution.

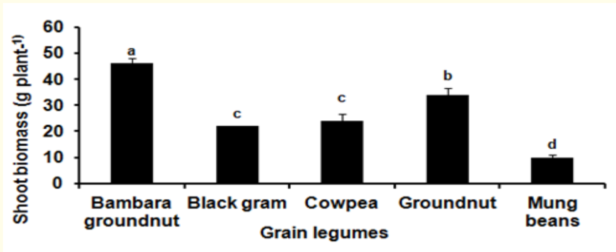

Figure 3.1: Shoot dry matter accumulation of five grain legumes grown under field conditions at Mbombela during the 2011/2012 cropping season.

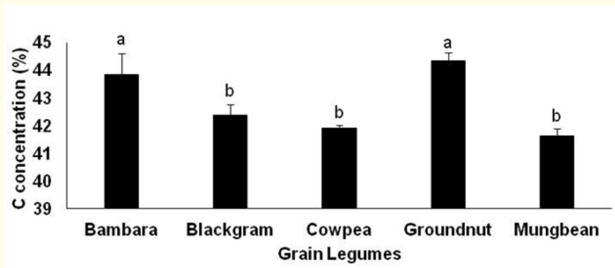

Figure 3.2: Shoot C concentration of five grain legumes grown at Mbombela, in the Mpumalanga province during the 2011/2012 cropping season.

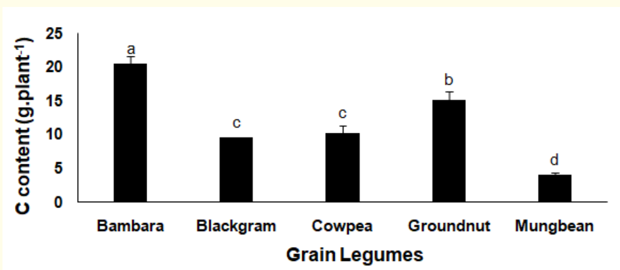

Figure 3.3: Shoot C content of five grain legumes grown at Mbombela, in the Mpumalanga province during the 2011/2012 cropping season.

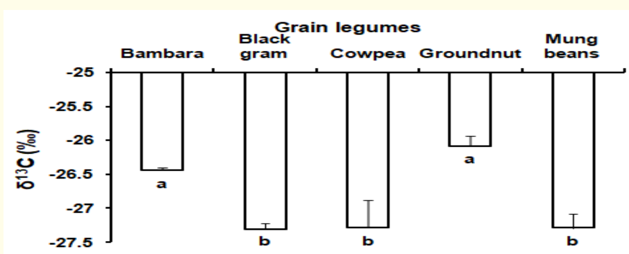

Figure 3.4: Shoot $\delta^{13}C$ of five grain legumes grown at Mbombela, in the Mpumalanga province during the 2011/2012 cropping season.

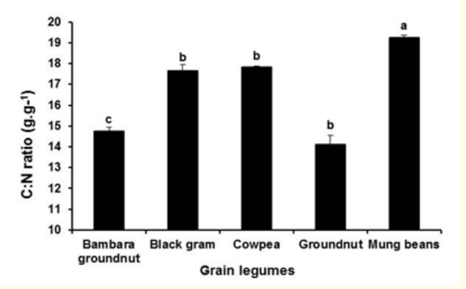

Figure 3.5: Shoot C:N ratio of five grain legumes grown at Mbombela, in the Mpumalanga province during the 2011/2012 cropping season.

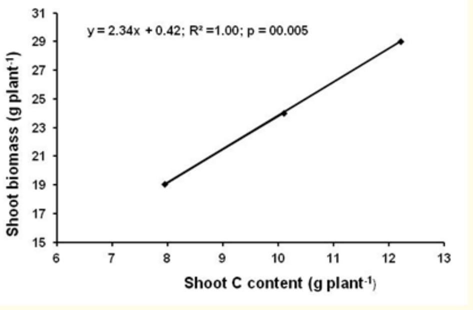

Figure 3.6: Relationship of C content and shoot biomass in cowpea planted at Mbombela in the Mpumalanga province during the 2011/2012 cropping season.

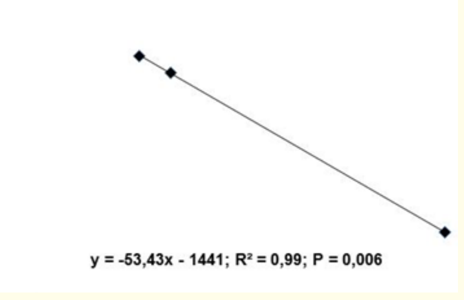

Figure 3.7: Relationship between pod yield and $\delta^{13}C$ of cowpea planted at Mbombela in the Mpumalanga province during the 2011/2012 cropping season.

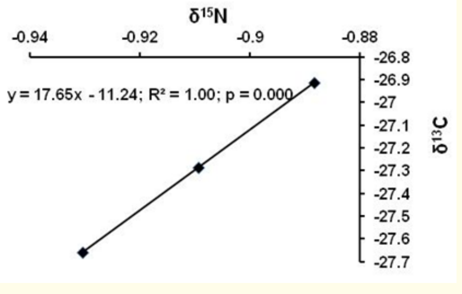

Figure 3.8: Relationship of $\delta^{13}C$ and $\delta^{15}N$ of mung bean planted at Mbombela in the Mpumalanga province during 2011/2012 cropping season.

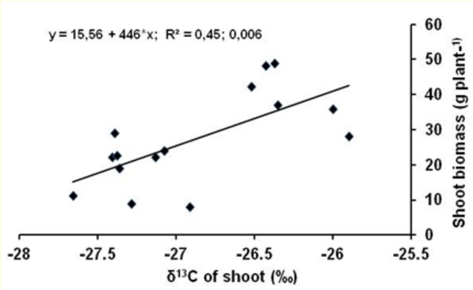

Figure 3.9: Relationship between shoot biomass and $\delta^{13}C$ (pooled data) of five grain legume species planted at Mbombela, Mpumalanga province, during the 2011/2012 cropping season.

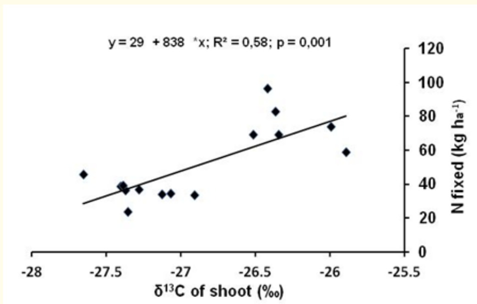

Figure 3.10: Relationship between N-fixed and $\delta^{13}C$ (pooled data) of five grain legume species planted at Mbombela, Mpumalanga province, during the 2011/2012 cropping season.

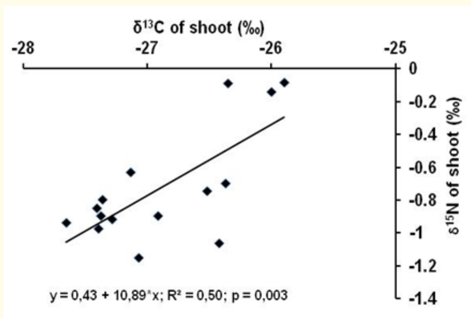

Figure 3.11: Relationship of ($\delta^{13}C$ with ($\delta^{15}N$ of grain legumes planted at Mbombela in the Mpumalanga province during 2011/2012 cropping season.

Discussion

The aim of this study was therefore to determine the C accumulation and WUE of five grain legumes using C isotopic discrimination ($^{13}C/^{12}C$) values during the 2011/2012 cropping season. South Africa is a semi-arid country with an annual average rainfall < 500 mm in two-thirds of its land mass (Marais, Annandale and Rethman, 2002). Under the highly variable, erratic and low annual rainfall conditions prevailing in South Africa, agricultural crops usually experience low soil moisture which can lead to low N accumulation in shoots, and consequently low dry matter production and low grain yield. Smallholder farmers practising rain-fed agriculture in SSA face recurring episodes of food insecurity, and food demand is expected to increase in the coming decades (Thornton *et al*., 2011).

Stability under intercropping is attributed to the partial restoration of diversity lost under monocropping, and the overall influence of enhanced soil organic matter content (Horwith, 1985; Onduru & Du Preez, 2007), Several studies have shown that co-planting of legumes and cereals increase grain and biomass yield due to enhanced biodiversity, water-use efficiency (WUE), efficient use of resources as well as control of insect pests, diseases and weeds (Eaglesham *et al*., 1981; Ofori & Stern, 1987; Rao & Mathuva, 2000; Osunde *et al*., 2004; Lithourgidis, *et al*., 2011) [35].

There is no literature available on the %C of cowpea, groundnut and black gram yet knowledge on such data could improve our knowledge on these plants' growth and C nutrition. A combination of these events causes poor agricultural production which results in detrimental effects on the livelihoods of largely low-income populations (Maluleke and Mokwena, 2017) [41]. The incorporation of legume residues and the rate of the residue's N transformation into organic matter is crucial especially in rotational systems. In plants, one way to predict N transformation is through the C/N ratio of the above-ground material (Hobbie, 1992) [16]. It indicates the extent to which N is released as a plant decomposes (Mulvaney *et al*., 2017) [36]. A low C/N ratio in plant tissue allows that their mineralization into organic matter by microorganisms, which typically have a low C/N ratio, happens quite faster (Nguyen and Marschner, 2016) [31]. In contrast, the mineralization of plant residues that contain a high C/N ratio can result in immobilisation of N in the microbial biomass (Moritsuka *et al*., 2004) [28]. Bambara groundnut sampled from farmers' fields in the Mpumalanga Province, South Africa showed shoot C/N ratio that ranged from 10.7-26.6 g/g, with 21 out of 26 farmers' fields with values ranging from 10.7-15.9 g/g (Mohale *et al*., 2014) [17].

Nodulated legumes, which derive their N nutrition largely from symbiotic fixation by root-nodule bacteria are relatively more drought-tolerant than non-legume crop species. In this context, legume-inclusive production systems, due to their capacity to fix atmospheric nitrogen (N_2) (Peoples *et al*., 1996) [15], can play a vital role in delivering multiple services as a nutritional food source (Voisin *et al*., 2014), and in mitigating greenhouse gas emissions (Lemke *et al*., 2007).

Under water stress, the partial closure of stomata leads to low discrimination against $^{13}CO_2$ during photosynthesis, resulting in a less negative $\delta^{13}C$ or greater water-use efficiency (WUE). Under these circumstances, less ^{13}C discrimination occurs, and less water is lost. Thus, $^{13}C/^{12}C$ isotopic discrimination values are considered a valuable tool for determining WUE, especially of C3 plants (Farquhar *et al*., 1989; Basu *et al*., 2003) [38]. Apart from water, soil productivity and crop yields depend on the availability of mineral nutrients, especially nitrogen (N) and phosphorus (P). There is a strong relationship between N nutrition and a plant's ability to tolerate drought.

Conclusion

Stability under intercropping is attributed to the partial restoration of diversity lost under monocropping, and the overall influence of enhanced soil organic matter content (Horwith, 1985; Onduru & Du Preez, 2007), Several studies have shown that co-planting of legumes and cereals increase grain and biomass yield due to enhanced biodiversity, water-use efficiency (WUE), efficient use of resources as well as control of insect pests, diseases and weeds.

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Thus these observations gave understanding of WUE and CO_2 interaction in plant leaves to enabled carbohydrates and proteins with other plant nutrients systematic function to give healthy plants status. Therefore breeding plants that are capable to use water efficiently can overcome drought stress to plants and improve crop production to smallholder farmers with positive achievements.

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Agriculture qualification.

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