WATER USE EFFICIENCY OF THREE COMMON SUBSISTENCE LEGUME CROPS IN RELATION TO SOIL TYPE UNDER CONTROLLED ENVIRONMENT CONDITIONS

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PREFACE

The research in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa.

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DECLARATION

I, Noxolo Nokukhanya Jila, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written, but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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Date: 02 November 2020

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ABSTRACT

Water scarcity in agriculture is the primary reason for poor crop yield and quality. The study's primary aim was to determine the effect of water stress on the growth and development of grain legumes in relation to the type of soil used for their production. A pot trial was used to grow three legume varieties (Gadra bean, Lima bean, and Peas) in five different soil types. The growing conditions were controlled for similarity, except for water availability. Adequate (75%FC), moderate (50%FC), and poor (30%FC) levels of water availability were imposed. Field capacity was measure by weight by filling a bare soil area with excess water inducing drainage, cover the wet soil with a plastic cover, wait about 2-3 days, collect a soil sample, weigh moist soil, dry in an oven at 105°C till to constant; weigh (after about 24 hours) and weigh the dry soil then moisture at field capacity was calculated. Crop response to water availability was determined by plant growth indices of time to flowering and plant size during growth. Crop performance was initially monitored in terms of crop establishment capacity as indicated by emergence.

Chlorophyll content index and stomatal conductance were used to determine plants' general physiological response during the vegetative phase of growth. Biomass accumulation and grain yield were determined at harvest by separating them into the aboveground total plant mass, root mass, and grain mass, respectively. Also, the availability of calcium (Ca), potassium (K), phosphorus (P), sodium (Na), Manganese (Mn), and magnesium (Mg) was determined in plant tissue after harvest. The results showed that plant height, number of leaves, number of seeds, dry grain weight, and plant dry weight of the three legumes responded significantly to water stress conditions. Chlorophyll content index and stomatal conductance showed significant differences in water availability. Calcium, P, and Mn increased with increased field capacity, but Mg and K decreased. Regardless of soil type and variety, crop performance declined with a decrease in water availability. Water stress was shown to have a rapid effect on legume performance, as indicated by highly significant differences between water availability levels during plant growth. Soil type has substantial interaction with water availability, mainly due to structural and chemical characteristics influencing water availability. Root mass is the most sensitive legume plant part of water stress than vegetative parts and grain responses to water stress's adverse effects.

Keywords: Field capacity, Growth parameters, Legume type, Soil type, Water stress

1. GENERAL INTRODUCTION AND RATIONALE

Legumes are viewed as one of the most significant field crops in South Africa by high protein content and dietary benefits (Mathobo, 2017). South Africa is renowned for its daylight, a normal of 2 500 hours of sun each year. It is a dry country and delegated semi-arid. The average annual precipitation for South Africa is 464 mm compared to the world average of about 860 mm (DEA, 2017). This is very challenging because it exposes legumes and other annual crops to water stress at different growth stages (DEA, 2017). In the world, legumes are grown in almost every climatic region and on a wide range of soil types (Daryanto, 2015). Legumes are not only used for human consumption but also animal feed and very important for soil improvement. They positively impact the yield when grown in rotation or cover crops with cereals since they increase soil carbon and nitrogen contents (Daryanto, 2015).

Increasing world population also brings environmental problems such as food scarcity, water scarcity, pollution, erosion, and deforestation (Heinemann et al., 2016). Water scarcity in agriculture is the primary reason for low crop yield and quality (Chaves, 2003). There is a need to improve crop water use efficiency and water productivity since agriculture is the biggest water consumer (Nhamo, 2016; Sharma and Molden, 2015). The situation is exacerbated by climate change (Rosegrant *et al., 2014*). Climate change has influenced the distribution of rainfall around the country and the world (Thornton et al., 2009). Higher temperatures, a drier environment, and increased climatic CO_2 are anticipated with environmental change in most temperate/subtropical zones. An increase in atmospheric CO_2 fixation increases photosynthesis and, consequently, nitrogen fixation (Redden et al., 2013).

In Sub-Sahara Africa (SSA), most legumes, ubiquitous beans are commonly grown by smallholder, research-poor farmers (Beebe et al., 2014). Drought is the limiting factor for crop growth and yield, decreasing crop biomass since it affects the plant photosynthesis processes (Reddy, 2004). Inadequate water fundamentally brings down the yield of many legume cultivars as most dry bean production in the world happens under rainfed conditions (Beebe et al., 2014). In this way, agriculture is under pressure to respond to a growing population's food security needs. Simultaneously, any moderate environmental change and its unfavorable impacts affect soil quality and the natural resource base (Lal, 2015). There is a need to consolidate information on legume cropping systems regarding the long-term maintenance of soil quality (Ness et al., 2010).

In agriculture, soil fertility is viewed as the status of soil concerning the presence of water, oxygen, and adequate and balanced nutrients to support plant requirements (Adeyeye, 2005; Fenta et al., 2012). Water stress (drought) is a significant constraint to crop production. Reduction in photosynthetic activity and increases in leaf senescence suggest water pressure and negatively affect crop development (Clauw et al., 2015). Significant effects of water stress include reducing nutrient uptake, thus reducing cell growth and enlargement, leaf expansion, metabolic assimilation, translocation, and transpiration (Mathobo et al., 2017). Plants effectively take up numerous nutrient elements; however, plant roots' capacity to retain water and nutrients generally decreases in water-stressed plants, probably as a result of a decline in the nutrient element demand above ground (Do & Akinci, 2017). Nutrient uptake from the soil solution is firmly connected to the plant root and soil water status. In the roots, disturbance of metabolism can be described by decreased root permeability because of deficient water availability and nutrient element uptake in the soil (Fageria & Moreira, 2011).

Many studies revealed that legumes are affected by the drought, resulting in lower crop yield (Asfaw, 2014). Dry bean seed yield reduction under stress can be attributed to the adverse effects of the pressure on individual yield components, including the number of pods per plant, the number of seeds in every pod, seed weight, and harvest index (Mayek-Pérez et al., 2002). Based on the study done by Emam *et al.*, 2010, drought has a negative impact on expected bean growth and seed yield. However, the ranges of reductions are highly variable due to differences in timing and intensity of the stress imposed and crop genotype. Although water is the limiting factor in legume growth studies, it can be manipulated by applying fertilizer or tillage (Meena & Lal, 2018). Crop rotation can be done to keep the soil's state in good condition (Ball et al., 2005).

The study's primary aim was to assess various legumes' agronomic performance in different soil types and their relation to water use efficiency. The specific objective was to determine legume growth, development, and yield in response to predetermined soil type differences under controlled environment conditions of crop water availability.

2. LITERATURE REVIEW

2.1 Importance of legumes

Common bean legumes or dry beans form part of the world's fundamental staple crops for direct human consumption (Complex & Together, 2019; Department of Agriculture, 2010). Legumes production differs within countries and around the world. This is due to different environmental conditions and thus genotype association. Soil and aerial climatic environment requirements (rainfall, solar radiation, etc.) have a major role with respect to crop adaptation and management. According to Joshi and Rahevar (2015), planting date also affects the production or yields of dry beans. Early planting in cool, wet soil may result in reduced yield due to inadequate heat units, while excessive radiation also compromises crop efficiency (Çakir et al., 2019). Compromising crop performance by neglecting environmental requirements may diminish the value of legumes. The crop's health benefits derive from direct attributes, such as their low grain saturated fat content and high content of essential nutrients and phytochemicals, as well as to displacement effects when they are substituted for animal products in the diet. They are rich in several important micronutrients, including potassium, magnesium, folate, iron, and zinc, and are important sources of protein in vegetarian diets (Craig, 2009). They are among the only plant foods that provide significant amounts of the indispensable amino acid lysine. Beans which do not meet human food quality standards can be utilized for feeding livestock (DAFF, 2010). Other uses It can be used for soil improvement because of its nitrogen fixation ability and as green manure, increasing organic matter in the soil thus is best to use it in a crop rotation cycle (Florentín et al., 2010). In this study, the effect of changing soil type and water availability during growth will be investigated.

Dry bean is a significant protein grain crop in South Africa developed generally for human utilization (Mathobo et al., 2017). The commonly utilized legume types include common bean (*Phaseolus vulgaris L.*), chickpea (*Cicer arietinum L.*), cowpea [*Vigna unguiculata (L.) Walp.*], groundnut (*Arachis hypogaea L.*), and pigeon pea [*Cajanus cajan (L.) Huth*] (Snapp et al., 2018). South African agriculture is dualistic in nature, comprising of the less developed/subsistence segment and a well-developed commercial sector. The quantity of commercial farmers is evaluated at between 50 000 and 60 000 and they produce in excess of 95 percent of total marketed agricultural output (FAO, 2005). It is important to investigate the possibility of expanding the subsistence production of legumes by looking into the effects of soil types and water availability.

2.2 Importance of water availability and water use efficiency

South Africa is considered as a water scarce country (Water, 2011). About 70% of residents of the Southern African Development Community (SADC) rely on dryland subsistence farming for their livelihoods (Dyer & Lamarche, 1982 ;(Gerster-Bentaya et al., 2015). Rainfed agriculture is subject to the hazards of climate, especially given that the region's precipitation patterns are characterized by serious fluctuation over the seasons, years, and decades. Southern Africa is anticipated to warm up faster than the rest of the world (Gerster-Bentaya et al., 2015). It is one of the few regions in the world that will encounter fundamentally drier conditions, increasingly unusual droughts, dry seasons, and floods. Figure 1 shows that southern Africa is prone to serious physical and economical water scarcity.

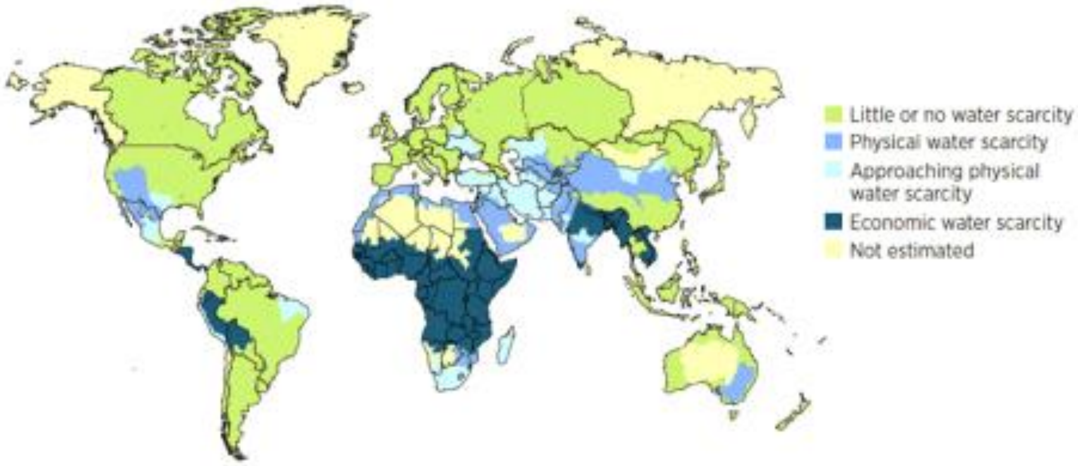


Figure 1. Areas of physical and economical water scarcity on the basin level in 2007 (Molden, 2013).

The improvement of water conservation, water quality and water-use efficiency are key national priorities in the context of a worldwide precipitation normal of 870 mm for every year, while the country only gets 450mm/annum (Stevens & Koppen, 2015). This makes South Africa the world's 30th driest nation (Mafuta et al., 2008). A few projections indicate that South Africa already exploits about 98% of its available water supply. Although irrigated agriculture utilizes exorbitant amounts of South Africa's available water resources, the significance of this for the economy and food security is undisputed (Mafuta et al., 2008). As more and more people migrate into cities from rural villages the pressure for the city to meet the water demands is ever increasing. There are many reasons that attribute to this growing water crisis in South Africa (Stevens & Koppen, 2015). Climate change has affected water supplies within the region. Rains that usually come and supply the country's water occur infrequently (Chibarabada et al., 2019). The role of agriculture stays significant despite its relatively small contribution to South Africa's gross domestic product (GDP).

2.2.1 Dry bean response to soil water availability and its water use efficiency

According to Jones (2004), water use efficiency (WUE) is defined as the ratio between photosynthesis and transpiration. WUE is also viewed in the context of evapotranspiration (ET) efficiency which includes losing water by soil evaporation (E). On the other hand, De Costa and Ariyawansha (1997) have defined WUE as the biomass increase per unit of water transpired. Water use efficiency depends on the soil's ability to capture and store water, the crop's ability to access stored water in the soil during the season, the crop's ability to change water into biomass, and the crop's capacity to change over biomass into economic yield. Water use efficiency can be improved by proper agronomic management practices and harvest versatility characteristics of the crop (Figure 2). Studies have been conducted on the effects of row spacing, planting date and water deficit on water use efficiency.

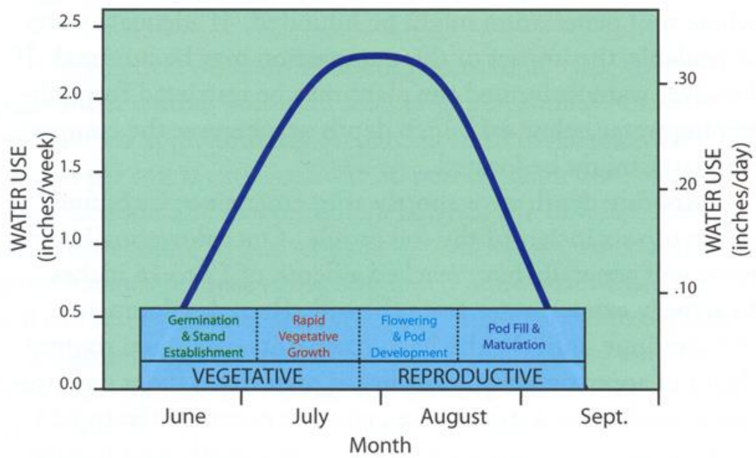


Figure 2: Peak water use by dry bean occurs during flowering and pod development (Source: https://cropwatch.unl.edu/drybeans/water).

Peak water use by dry bean happens during blossoming and pod development (Figure 2). Since the peak water use for dry bean corresponds with the important development stages and times of highest evapotranspiration, the dry bean crop is most sensitive to water stress during this time period. Water use rates vary every day during the growing season. Cool days even during the peak water use period may result in significant variation of day by day water use rates by the crop.

2.3 Drought tolerance by legumes

2.3.1 The effect of water stress on agronomic performance of legumes

Drought stress induces various physiological and biochemical adaptations in plants. Among physiological processes, gas exchange processes are one of the most important ones. Differences between tolerant and sensitive genotypes within species have been shown (Khaliq & Ahmed, 2016). According to Fenta et al. (2014), drought stress reduced leaf water potential and gas exchange characteristics (CO_2 assimilation and stomatal conductance). Mathobo et al. (2017) reported that drought stress reduced photosynthetic rate, intercellular carbon dioxide concentration, stomatal conductance, transpiration, and chlorophyll fluorescence.
According to the study done by Khaliq & Ahmed (2016) on the effect of drought stress on gas exchange characteristics of four soybean genotypes, plants grown under water stress conditions showed less photosynthesis than those grown under non-stress conditions. Water stress conditions significantly decreased the stomatal conductance of leaves in all the genotypes studied. Decreased stomatal conductance due to water stress was also observed in soybean leaves by Makbul et al. (2011). Many reports agreed with Khaliq & Ahmed (2016), including Ohashi et al. (2012), who reported the effect of water stress on growth, photosynthesis, and photoassimilate translocation on soybean and tropical pasture legumes (Figure 3 and Table 1).

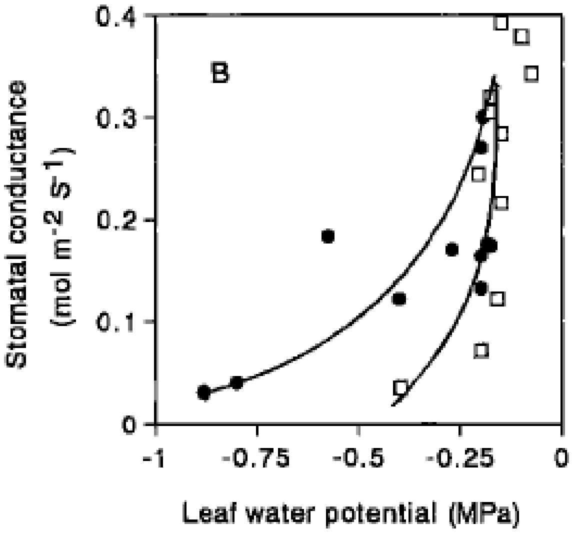


Figure 3. Relationship between leaf water potential and stomatal conductance in soybean and Siratro under water stress conditions (Ohashi et al., 2012).

Table 1 shows the effect of water stress on stomatal conductance in different species of legumes (Soybean and Siratro). Water stress decreases the stomatal conductance and a decrease in the stomatal conductance in soybean occurred at a higher leaf water potential than in siratro

Table 1 Effect of water stress on stomatal conductance

	Species	Treatment	Days after treatment		
			3	7	21
Leaf water potential (- MPa)	Soybean	Control	0,18	0,15	0,15
		Water stress	0,16	0,22	0,35
	Siratro	Control	0,2	0,19	0,18
		Water stress	0,21	0,27	0,8
Stomatal conductance (mol m^{-2} s^{-1})	Soybean	Control	0,38	0,39	0,39
		Water stress	0,33	0,08	0,03
	Siratro	Control	0,3	0,33	0,33
		Water stress	0,29	0,16	0,05

(Ohashi et al., 2012)

Stomatal conductance was also strongly affected by the changes in the leaf water potential (Figure 3). Stomatal conductance decreased as the leaf water potential decreased in both soybean and siratro. The decrease in stomatal conductance with reducing leaf water potential was more substantial in soybean than in siratro, indicating that stomata's sensitivity to low leaf water potential conditions was higher in soybean than in siratro. Although stomatal closure by water stress is associated with a leaf water deficit, in Ohashi's experiment, a decrease in the stomatal conductance in soybean occurred at a higher leaf water potential than in siratro.

2.3.2 Effect of water stress on the uptake of nutrients of legumes

Soil is an essential anchor to support plant growth, and when adequately fertilized, gives a meaningful crop yield. Common plant response to insufficient nutrient supply involves physiological changes, and nutrient availability plays a vital role in plant development. Numerous essential plant nutrient elements regulate plant metabolism, even underwater stress, by acting as co-factors or enzyme activators (Adeyeye, 2005; Do & Akinci, 2017; Berhanu Amsalu Fenta et al., 2014). In agriculture, soil fertility is considered to be the status of soil with respect to the presence of water, oxygen, and adequate and balanced nutrients, as well as the presence of a favorable ionic composition in the form the plants need for optimum growth (Do & Akinci, 2017). Water stress (drought) is also an important limitation to crop production. Reduction in photosynthetic activity and increases in leaf senescence are symptomatic of water stress and adversely affect crop growth. Other effects of water stress include a reduction in nutrient uptake, reduced cell growth and enlargement, leaf expansion, assimilation, translocation and transpiration. Many nutrient elements are actively taken up by plants, however the capacity of plant roots to absorb water and nutrients generally decreases in water stressed plants, presumably because of a decline in the nutrient element demand. In a study done by Doğan & Akinci (2017), the influence of two levels of water stress on *Phaseolus vulgaris L*. plants was investigated. It was found that the concentrations of K^{+} and Mg^{2+} were significantly decreased under severe stress treatments. Zn^{2+} and Mn^{2+} content increased in the leaves of both moderate and severe stressed conditions, while Ca^{2+} and Fe^{3+} decreased under severe stress compared to control values. Na^{+} content of leaves was measured, but in all cases was below the limits of detection. Also, in a different study (Shakiba et al., 2014) it was shown that the Fe content of seeds was severely affected under drought stress and was reduced in all stages, while the seed nitrogen content was affected the least under these conditions. Drought stress reduced the accumulation of iron, zinc, and phosphorous in plants mainly at the developmental stages.

The influence of drought stress on different genotypes of dry bean varies (Darkwa et al., 2016). According to (Beebe et al., 2014) some common bean genotype respond to drought stress by reaching their maturity quicker. Based on published work (Agricultural, 2011) done on genetic variation for drought resistance in small red-seeded common bean genotypes, it was found that late maturing genotypes suffer great reduction in performance under drought stress than early ones. The yield, chlorophyll content, plant height and many other performances decrease in late maturing genotypes. Based on the study done by Fening and Quansah (2009) on the response of three forage legumes to soil moisture stress, it was reported that water stress affects the growth of forage legumes in direct relationship with plant nutrient content and crop type (Figures 4 and 5).

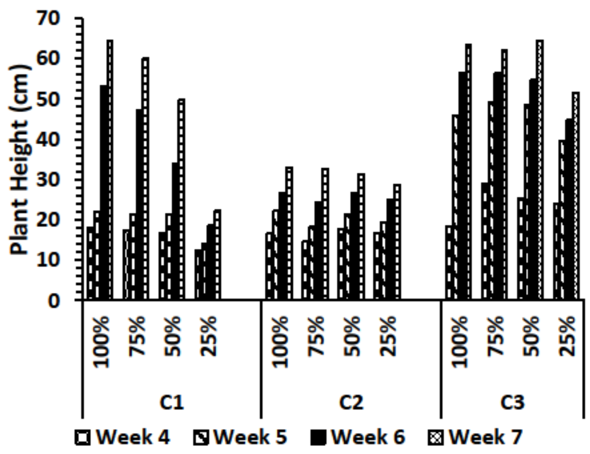


Figure 4. Effect of crop type and moisture stress on plant height (cm) at four sampling periods (Fening and Quansah, 2009).

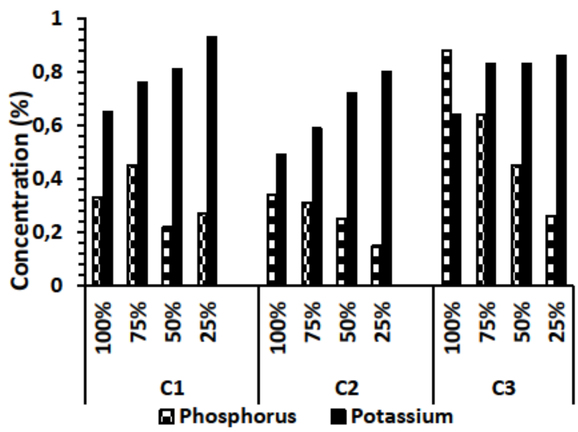


Figure 5 Effect of crop type and moisture stress on phosphorus and potassium concentration (Fening and Quansah, 2009).

This study showed that the effect of water stress is determined by the genotype as some genotypes are more resistant to water stress compared to others. These findings were confirmed by Emam *et al.* (2010) (Table 2; Figures 6 and 7). Two common bean cultivars with contrasting growth habits were grown under different water availability levels in terms of field capacity (100%, 75%, 50% and 25%). The findings showed that plant height, number of leaves, leaf area, number of pods, pod dry weight and total dry weight responded significantly to water stress conditions. Water stress also reduced stem height and reduced leaf area. Furthermore, it reduced pod dry weight.

Table 2 :Effect of water stress levels on plant height (cm) of two common bean cultivars (Emam et al., 2010).

Treatments	**Water stress levels (% of field capacity)**			
Common bean cultivar	**100%**	**75%**	**50%**	**25%**
D81083	35,250c	29,500d	24,750e	22,750e
Sayyad	51,000a	43,250b	36,000c	30,000d

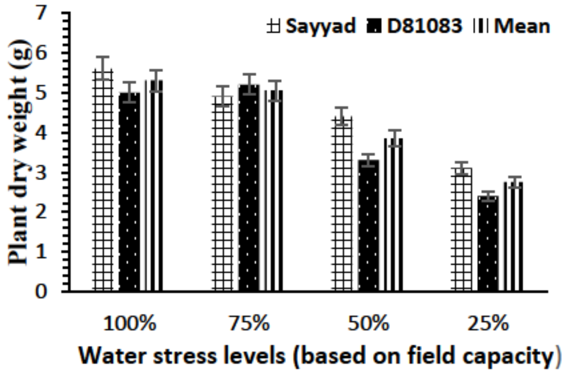


Figure 6. Effect of water-stress levels on common bean dry weight (Emam et al., 2010).

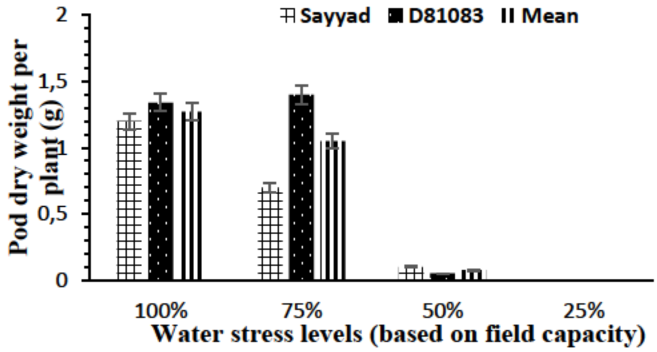
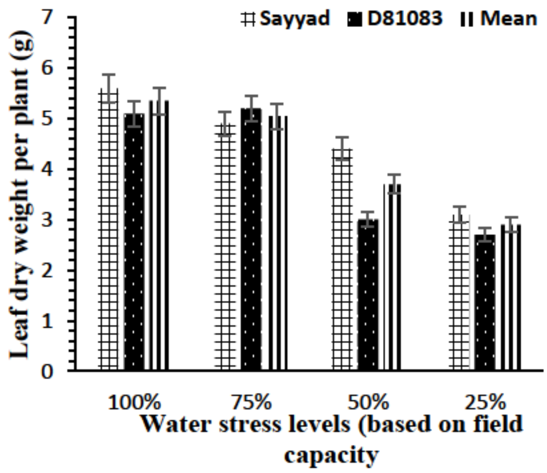


Figure 7 Effect of water-stress levels on common bean pod dry weight (Emam et al., 2010).



Effect of water-stress levels on common bean leaf dry weight (Emam et al., 2010).

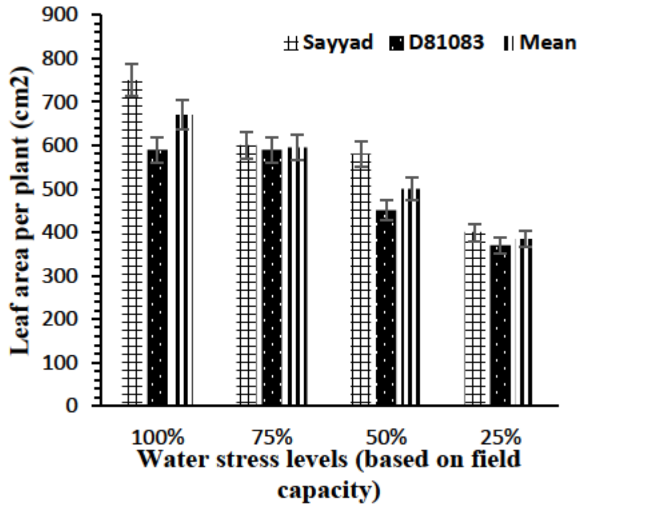


Figure 8 Effect of water-stress levels on common bean leaf dry area (Emam et al., 2010).

This study concluded that overall, drought stress has a highly significant effect on common bean growth and seed yield although the ranges of reductions are affected by contrasts in timing and intensity of the stress imposed and genotype utilised

2.4 Importance of soil type on legume production

2.4.1 Soil type and field capacity

Field capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased (Houston, 1965). This usually takes place 2–3 days after rain or irrigation in previous soils of uniform structure and texture. Figure 10 illustrates the moisture content in the soil is mainly affected by the texture of the soil.

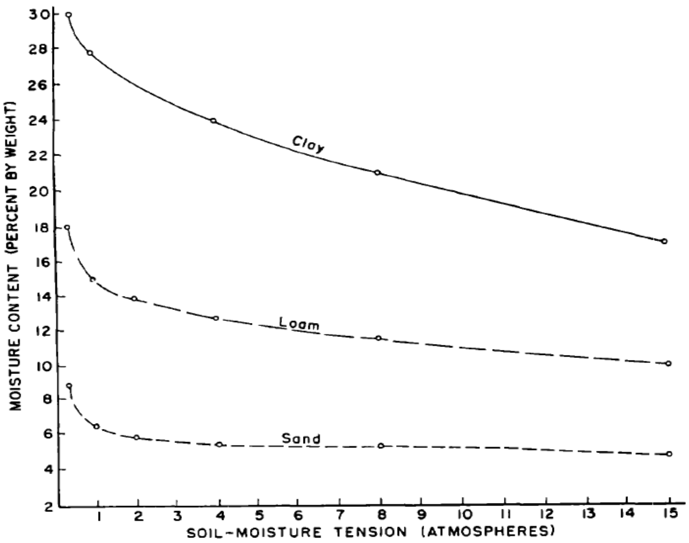


Figure 9 Moisture characteristic curves of different textures of soil (Houston, 1965).

According to the results obtained by Houston (1965), as the soil drains, the largest soil pores empty first since the capillary forces are smallest in these pores. As the soil drains further, the maximum diameter of the water-filled pores further decreases, corresponding with pores that have decreasing values for the pressure potential (larger capillary forces hold water). Sandy soils may drain within a few hours but fine-textured soils such as clay may take a few days to drain this is affected by different factors which includes the following:

(i) Soil texture and structure

These change with soil horizon and influence water retention. Clayey soils retain more water, and longer than sandy soils. The finer the texture is, the higher is the FC, the slower is its attainment, and the less distinct is its value (Hillel, 2012).

(ii) Type of clay

Montmorillonite swells with the addition of water. Montmorillonites expand considerably more than other clays due to water penetrating the interlayer molecular spaces and concomitant adsorption. The higher the content of montmorillonite is, the greater is the content of water.

(iii) Organic matter

According to the findings of Fileccia and Guadagni, 2014, an increase in organic matter in the soil, more water is retained or held by the soil. Organic matter works like glue keeping soil particles together improving their structure. Thus, organic matter increases the resistance of soil to mechanical disturbance, such as those produced by raindrops falling on the ground. That is why fertile soils with high organic matter content are more resistant to heavy rains, less prone to erosion, and have higher infiltration.

(iv) Evapotranspiration

The rate and pattern of extraction of water by plant roots from soil can affect the gradients and flow directions in the profile and modify redistribution (Hillel, 2012).

(v) Temperature

The temperature influences the amount of water held, particularly if the soil has been previously wetted. The amount of water retained at FC decreases as the soil temperature increases (Kramer, 1983).

Table 3 below illustrates the different legume crops which include soya bean, groundnut, dry bean and peas with respect to soil type requirement. The soils are basically well drained for all crops.

Table 3: Different legume crops with their soil requirement for a good yield.

Crop	**Soil requirement**	**Reference**
Soya Beans	Deep well drained soils, optimum pH from 6 to 6.5, Sandy loam to sand clay (15% - 50% clay).	(Cilliers, n.d.; DAFF, 2016)
Groundnuts	Grow best in red-coloured, yellow-red and red, well-drained, pH range of 5,5 to 7,0. Loamy sand to Sandy loam (10% to 20% clay).	(Department of Agriculture Forestry Fisheries, 2011)
Dry bean	Well drained soils, Sandy loam, sandy clay loam or clay loam with a clay content of between 15 and 35 % is suitable.	(Department of Agriculture, 2010)
Peas	Peas can be grown on all types of soils, but it prefers well-drained sandy loam soils. Optimum pH from 6.0 to 7.5.	(Department of Agriculture Forestry Fisheries, 2011)

Soil type can be associated with soil pH, which has a direct effect on plant growth. A previous study (Fageria & Baligar, 1999) clearly showed the percentage accumulation of aboveground biomass in soybean and common bean in response to soil pH (Table 4).

Table 4: Relative dry matter yield of shoots (%) of five crop species under different (Fageria & Baligar, 1999).

pH in water	Soybean	Common bean
4,9	80	49
5,9	64	91
6,4	69	59
6,7	55	64
7,0	35	56

It was concluded that an increasing the soil pH from 4.9 to 6 provided an environment more conducive to shoots growth. Furthermore, an increasing yield with increasing soil pH of the inceptisol was associated with decreasing toxicity of Mn and improved Ca nutrition in the crops. In general, at higher pH (>6), decrease in uptake of micronutrients might be responsible for decreased yield of crops.

3. MATERIALS AND METHODS

3.1 General statement

A greenhouse study was carried out to investigate the impact of different water stress levels as a percentage of field capacity (by weight) on the growth and development of three legume cultivars of Gadra bean, Lima bean, and Peas. Seeds were sourced from McDonald's Seeds (Pty) Ltd in Pietermaritzburg KwaZulu-Natal. The research was conducted on the premises at the University of KwaZulu-Natal's College of Agriculture, Engineering and Science campus, Pietermaritzburg, South Africa (29º37'39.72' 'S, 30º24'09"E). An experiment (pot trial) was conducted in the greenhouse to determine the three legume varieties' physiological performance using different soil types collected from five various sites in KwaZulu-Natal, South Africa.

3.2 Description of legume crops used

Gadra bean (*Phaseolus vulgaris*) is a common bean characterised by an upright, bush growth habit developed as an early harvest sugar bean. It performs well in the late planting slot in all areas when other legumes varieties will not make it through (McDonald's Seeds, 2019) (Figure 10A). Lima bean is a herbaceous plant with two main types of growth habits. The perennial form is an indeterminate, vigorous, climbing, and trailing plant. The annual lima bean is a pseudo-determinate, bushy plant (Baudoin, 2006) (Figure 10B). Peas (*Pisum sativum*) is an annual cool-season crop. The immature pods are used as a vegetable. Green feast is a climbing plant and more tolerant to heat than most peas and keeps producing even as the weather warms up (Baudoin, 2006) (Figure 10C). The experiment was undertaken under greenhouse conditions at the University of KwaZulu- Natal, South Africa. Properly controlled heat and humidity are essential to the greenhouse's success. The temperature was kept constant at 27ºC day/15ºC night, and the humidity was 65%.

Figure 10 A. Gadra bean, B. Lima bean and C. Greenfeast pea.

3.3 Soil properties

Five different soil types were used, which were collected from different areas in the province of KwaZulu Natal: Swayimane (Wartburg) (29° 26' 0" S; 30° 35' 0" E), Richmond (30° 24' 59.99" S; 30° 28' 59.99" E), Howick (29° 29' 21.462"S; 30° 12' 59.9472"E), Deepdale (29°45'0" S; 29°55'0" E) and Mooi River (29° 12' 0" S, 29° 59' 0" E). Table 5 and Table 6 illustrate the background information about the sites where the soils were collected as well as some physical characteristics. Table 7 illustrates the chemical properties of the soils.

Table 5. Soils land-use history before the trial.

Area	Land previous information	Soil group (Fey, 2010)
Richmond	Old citrus orchard (20 years)	Organic
Deepdale	Fallow - natural grazing veld	Humic
Howick	First generation eucalyptus forest	Vertic
Mooi River	Fallow – undisturbed open land	Podzolic
Swayimane	Recently cultivated land – previous maize	Humic

Table 6 Depth (cm) and colour of experimental soils

	Depth (cm)		Colour		
Study site	A horizon	B horizon	A horizon	B horizon	C horizon
Richmond	60	45	5YR 3/2	2.5YR 3/4	2.5Y 6/6
Deepdale	30	60	2.5YR 2.5/4	2.5YR 3/6	7.5YR 5/4
Howick	37(O);20(A)	20	10YR 2/1(O); 10YR 3/6(A)	7.5YR 3/4	7.5YR 5/4
Mooi river	30	25	10YR 3/4	2.5YR 3/4	7.5YR 7/6
Swayimane	25	55	10.5YR 3/2	10R 2.5/2	2.5YR 4/8

Table 7 shows physical and chemical properties of experimental soils before planting. Soil samples were analysed at Cedara (29° 31' 59.99" S and Longitude: 30° 16' 60.00" E). The Soil Fertility Laboratory routinely performs the following analyses as part of the Department’s Fertilizer Advisory Service using the rapid procedures described by Manson & Roberts, 2001: Ambic-2-extractable P, K, Cu, Mn and Zn, KCl-extractable Ca, Mg and acidity, and pH (KCl); NIRS-estimates of organic carbon and clay content are also done routinely. Other soil analyses done by the Section are EC, Ca, Mg, K, and Na in the saturation extract, ammonium-acetate extractable Na, pH (water), total carbon, nitrogen, and sulphur, Walkley-Black organic carbon, and particle size distribution.

Table 7. Some physical and chemical properties of experimental soils before planting. Values sharing the same letters were not significantly different (p ≤0.05)

				P (mg/L)	**K**	**Ca**	**Mg**	**Zn**	**Mn**		
Soil	**pH**	**N (%)**	**Exchange acidity (cmol/L)**							**Org.C (%)**	**Clay (%)**
Swayimane	4,51c	0,41c	0,37b	78,67b	164,70b	719,70ab	196,70b	15,77b	8,00a	5,77d	32,67a
Richmond	4,58c	0,42c	0,29b	81,67b	217,70c	989,00c	173,00b	12,17b	12,67a	5,57d	49,33c
Howick	3,77a	0,34b	2,39d	11,33a	92,00a	693,00a	142,00a	1,53a	47,33c	4,40c	43,67bc
Mooi river	4,23b	0,17a	0,64c	6,67a	85,70a	522,70a	339,00c	0,10a	13,67a	3,17b	47,33c
Deepdale	4,84d	0,15a	0,11a	6,67a	285,70d	927,00bc	463,70d	0,97a	30,33b	1,90a	37,33ab

3.4 Experimental design and data analysis

A completely randomised complete bock pot trial was designed with five soil types as the main blocks, three legume types of as main plots, and four water stress levels as sub-treatment plots. The soil types are described in Table 7. The legume types are shown in Figure 11. Based on soil-specific field capacity (FC) to a depth of 100 cm, water stress treatments were 75% FC, 50% FC, and 30% FC, respectively. The pots were weighed in two days intervals to compensate for the water loss by evapotranspiration. Field capacity was measure by weight by filling a bare soil area with excess water inducing drainage, cover the wet soil with a plastic cover, wait about 2-3 days, collect a soil sample, weigh moist soil, dry in an oven at 105°C till to constant; weigh (after about 24 hours) and weigh the dry soil then moisture at field capacity was calculated.

The pot size was 2 kg of soil. The experiment was replicated three times. Data collected were subjected to analysis of variance (ANOVA) using statistical package GenStat® Version 18 (VSN International, United Kingdom) at the 5% probability level of significant difference (P≤0.05). Duncan's multiple range test on GenStat® at the probability level of 5% was used to compare means.

3.5 Plant growth and development determination

Four seedlings per pot were planted (5 cm) to determine filed germination (emergence) and then thinned to one seedling per plot after full emergence (VE). From this stage onwards, there was non-destructive evaluation of plant growth and physiology parameters on a weekly basis. Plant height was measured from the ground level to the tip of the fully matured leaf using a measuring tape (Stanley 3 m Power lock steel tape measure) until flowering. Leaf number was counted from the V1 stage, the first trifoliate until flowering. Stomatal conductance (SC) was determined using the Model SC–1 steady state leaf porometer (Decagon Devices, Inc., USA). A portable chlorophyll meter, the SPAD-502 Plus (Konica Minolta, Japan) was used to measure chlorophyll content index (CCI) on the fully expanded trifoliate and solar radiation exposed leaves. Plants were harvested at full senescence. Aboveground fresh mass was determined using a digital sensitive balance (Masskot, FX320, Switzerland). Pods were shelled to determine seed number and grain mass per plant.

3.6 Plant chemical analysis

One gram of oven dry (105 °C) homogenized plant material was ashed in a muffle furnace at 500 °C for 4 hours. The ash was then digested by gentle heating on a hotplate in 5 ml of 16% hydrochloric acid in silica crucibles. The digested samples were filtered through pre-wetted Whatman no. 42 filter paper (Merck, Germany) and made up to 50 ml with deionized water in a volumetric flask, for further analysis. Mixed standard solutions were prepared from certified reference standards (De Bruyn Spectroscopic Solutions, South Africa) for Ca, K, Mg, Na, Fe, Mn, Cu, Fe, Zn, P, and B. Samples were analyzed on an MP-AES 4200 (Agilent, USA) against standard reference curves and results were reported in mg kg^{-1} .

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Crop agronomic performance

4.1.1 Introduction

Environmental stresses, both biotic and abiotic, trigger a wide variety of plant responses ranging from altered gene expression and cellular metabolism to change in growth rate and crop yield (Reddy et al., 2004). The effects, which include drought, salinity, light, pathogen infection and high temperatures are potentially harmful to growth and productivity of legumes. Many studies have indicated that drought is the one of the most adverse factors which affect the growth and productivity of a legume crop (Adams et al., 2016; Farooq et al., 2017; Mathobo et al., 2017; Sharma et al., 2015). Plant growth is affected under prolonged drought conditions. For example, the leaf biomass and growth rate of *Archontophoenix cunninghamiana* decreases in dry conditions (Sheppard et al., 2016). Chaudhari et al., 2017 reported that tomato plant height decreased under two drought-stress treatments (3 days of drought-stress before metribuzin application with no drought-stress after application, and three days of drought-stress before metribuzin (Berhanu Amsalu Fenta et al., 2014). Reduction of leaf number and plant height is considered a phenotypic mechanism for controlling water use efficiency and reducing oxidative injury under drought stress conditions (Fenta et al., 2012). During water stress, osmotic adjustment is increased to avoid dehydration and improve yield under water stress (Berhanu Amsalu Fenta et al., 2014; Hlanga, 2017). Under the water stress cell expansion slows down or ceases, and plant growth is retarded. However, water stress influences cell enlargement more than cell division. Plant growth under drought is influenced by altered photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and hormones.

Photosynthesis is an essential process to maintain crop growth and development, and it is well known that photosynthetic systems in higher plants are most sensitive to drought stress. Chlorophyll is one of the major chloroplast components for photosynthesis, and relative chlorophyll content has a positive relationship with photosynthetic rate. Based on the study done by Mathobo(2017) about the effect of drought stress on yield, leaf gaseous exchange and chlorophyll fluorescence of dry beans (*Phaseolus vulgaris*) it was reported that the reduction of chlorophyll content is due to drought which affects the leaves initially by decreasing chlorophyll content as a result of damaged chloroplasts caused by oxygen species. Drought stress progressively decreases carbon dioxide assimilation rates due to reduced stomatal conductance. It also induces reduction in the content and activity of photosynthetic carbon reduction cycle enzymes (Adams et al., 2016; Reddy et al., 2004). Hence, stomatal conductance reduces transpiration and diminishes the essential roles in regulating plant water balance. Stomata closure also reduces cell expansion and growth rate, leading to a significant reduction in biomass and yield. Many scientists believe that the first reaction of virtually most of the plants to severe drought is the closure of their stomata to prevent the water loss via transpiration. Stomata closure results from direct evaporation of water from the guard cells with no metabolic action. On the other hand, when soil-available water content reduces, the stomata open less or even remain closed. By keeping stomata closed under drought conditions, the plant minimizes dehydration (Clauw et al., 2015; Osakabe et al., 2014; Pirasteh-Anosheh et al., 2016). Stomatal closure in response to drought stress primarily results in decrease in the photosynthesis rate. Previous studies (Mutava et al., 2015) revealed that under drought stress, stomatal conductance of soybean is responsible for reduced photosynthetic rate. It disrupts photosynthetic pigments and reduces the gas exchange leading to reduction in plant growth and productivity.

4.1.2 Crop establishment

Crop establishment begins with germination, which is basically seed radicle protrusion and does not guarantee seedling establishment. Under conditions of plant growth, seedling emergence is used as an indicator of initial crop establishment. When seed quality is poor, seedling emergence may not occur or will be low and compromise final crop establishment. This study relied on commercial seed in compliance with seed testing requirement of 100% germination. Maximum emergence, representative of the seed lot was enhanced by planting four seedlings per pot in order to thin plant numbers to one plant per plot after seedling establishment (V1 stage).

There was a significant ($P = 0.05$) difference between sites (representing different soils) with respect to seedling emergence. A more significant difference ($P = 0.01$) was observed between water stress levels (Figure 11). Legume types showed a significant difference ($P=0.05$) with respect to emergence in response to water stress. It must be noted that the results of seedling emergence were determined before thinning. Therefore, for the remainder of the experiment, all pots had plants for a balanced experimental design as planned.

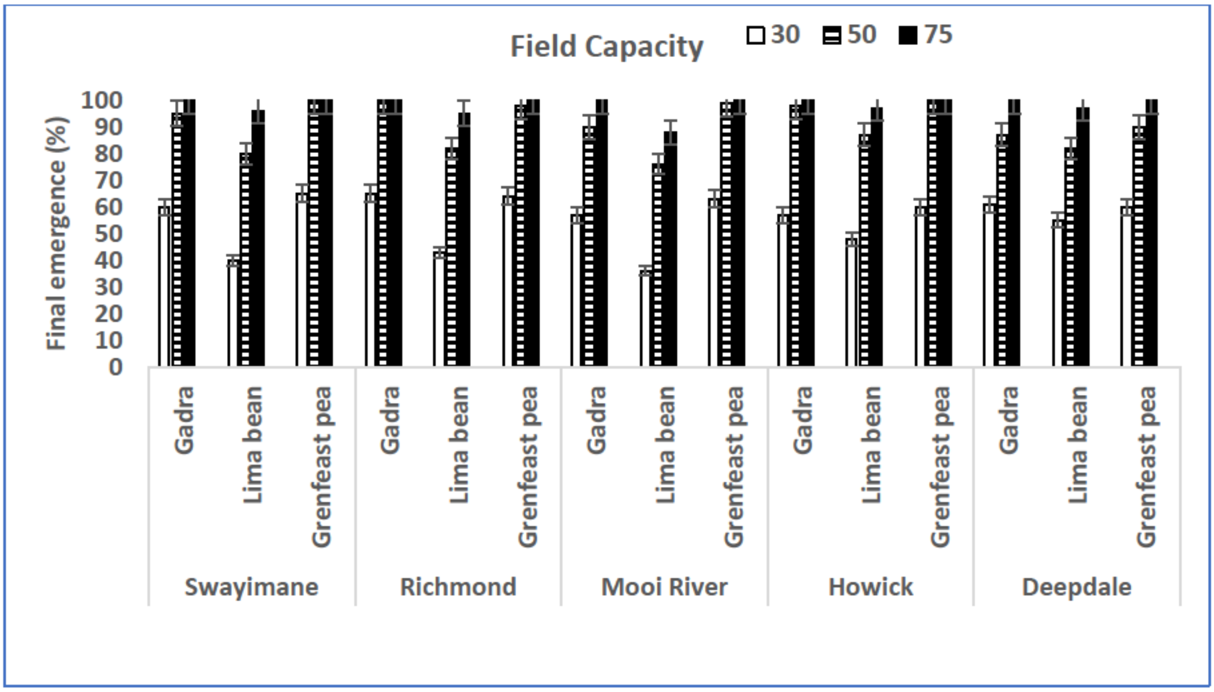


Figure 11 Final seedling emergence of three legume types (Gadra, Lima bean and Greenfeast pea) grown in soils from different sites (Swayimane, Richmond, Mooi River, Howick and Deepdale) in response to three levels of water stress treatment indicated as field capacity (30% FC, 50% FC and 75% FC).

In this study, crop emergence was significantly affected by water deficit stress, indicating that the seed germination is more sensitive to water stress. This result agrees with that of Bayu et al. (2005) who observed a greater effect of water deficit stress on germination percentage. Many studies conducted until now have proven that the increasing water stress decreases the germination proportion in many species (Boydak et al., 2003; Gülcü et al., 2010; Temel et al., 2011).

4.1.3 Plant growth and development

The general pattern of plant growth during the vegetative stages in response to water stress is shown in Figure 12. It is clear that water stress significantly ($P \leq 0.05$) reduced plant growth reduced plant growth of all legume types.

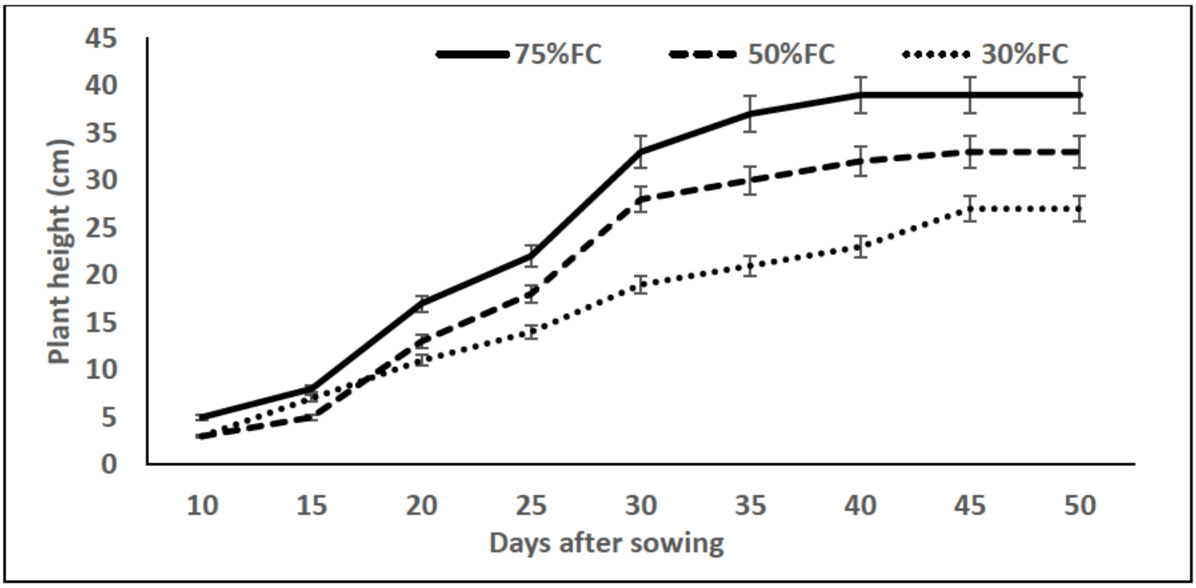


Figure 12 General pattern of plant growth for the three legume types studied when grown in five soil types at three levels of water stress, indicated by field capacity (FC).

Table 8 is a summary of the means for all factors affecting plant growth, including grain yield per plant, plant height (cm), leaf number, pod number per plant.

Table 8 Factors affecting legume type growth, development and grain yield under controlled environment conditions

Factors	Days to 50% flowering	Days to 90% seed maturity	Plant height (cm)	Leaf number	Pod number plant^{-1}	100 grain mass (g)
Sites						
Swayimane	52c	110.1cd	39.3bc	22a	6.5c	17.7c
Richmond	53cd	108.2c	36.2b	23ab	5.4ab	16.4b
Moi River	46a	104.1c	34.1b	21a	4.3a	14.1a
Howick	51c	98.3b	33.3b	22a	5.0a	15.3b
Deepdale	48b	90.3a	28.1a	20a	4.8a	14.2a
LSD(0.05)	1.1	5.3	3.7	2.0	1.5	1.2
Legume types						
Gadra bean	55b	105.4b	39.2ab	22.4b	7.2a	16.5b
Lima bean	47a	117.3c	35.4a	25.3c	5.5a	22.3c
Greenfeast pea	36a	86.9a	37.0a	18.6a	6.3a	12.4a
LSD (0.05)	2.3	4.1	2.8	2.2	2.0	2.5
Water stress levels						
30% FC	44.1a	76.6a	27.2a	15.1a	13.4a	12.7a
50% FC	50.2b	112.3b	33.4b	22.1b	17.9b	15.6b
75% FC	56.5c	119.1c	38.2c	27.3c	22.4c	19.7c
LSD (0.05)	3.4	4.3	2.6	3.1	3.8	2.3

The soils used in this study differed significantly ($P < 0.05$) with respect to growth of the three legume types. Therefore, the response of crops to grow under water stress was also related top the type of soil used. For all determinants of vegetative plant growth and development, including plant size, leaf number and time to flowering, there was a significant pattern showing that the lower the field capacity, the less efficient is plant growth (Table 8). Increasing water stress from the normal 75%FC to 30%FC reduced plant height by about 30%. Increasing water stress from the normal 75%FC to 30%FC delayed time to flowering by 22%.

The relationship between crop performance and the major experimental factors of soil, legume variety and water stress were observed respectively as shown in Figures 13, 14, 15, 16, 17 and 18. Plant size (height) is a measure of plant response to availability of soil water and nutrients, also known as growth. Crop yield is a measure of crop performance at the end of vegetative growth and seed ripening, which are supported by soil water and nutrients. In this context, it was necessary to define a correlation between the time taken by the different legume types to finalise vegetative growth, i.e., time to flowering, with plant size (height) and crop yield (grain mass.

Figure 13 shows that on a liner basis and across soil types (sites), time to flowering (growth period) and plant height (growth index) are highly related ($R^2 = 0.947$).

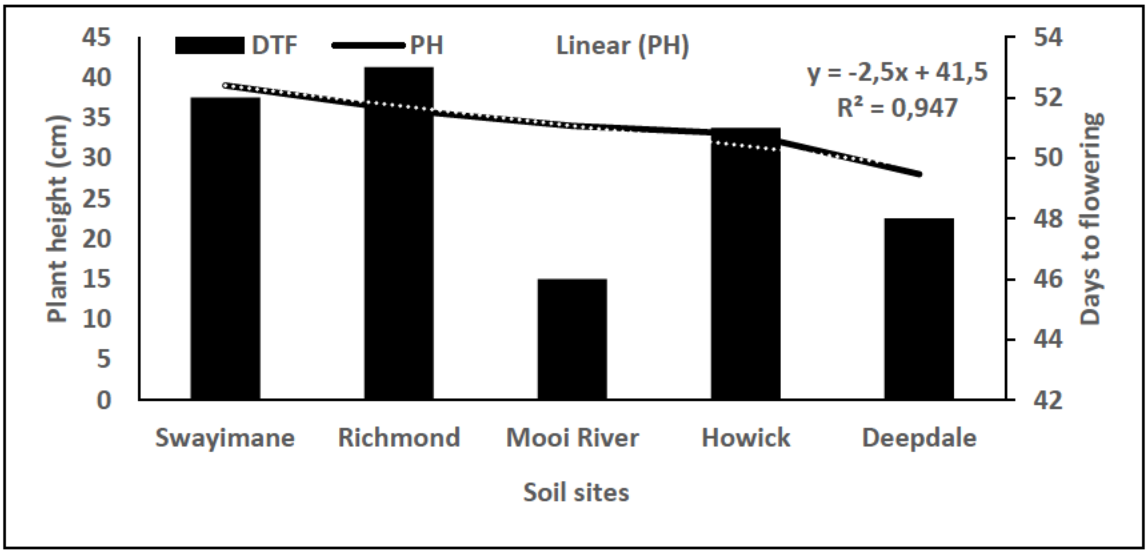


Figure 13 Correlation of legume plant size with time to flowering as affected by soil type (soil sites).

Figure 14 shows that, on a linear basis, irrespective of legume type, time to flowering and plant height (growth index) are directly correlated ($R^2 = 1$).

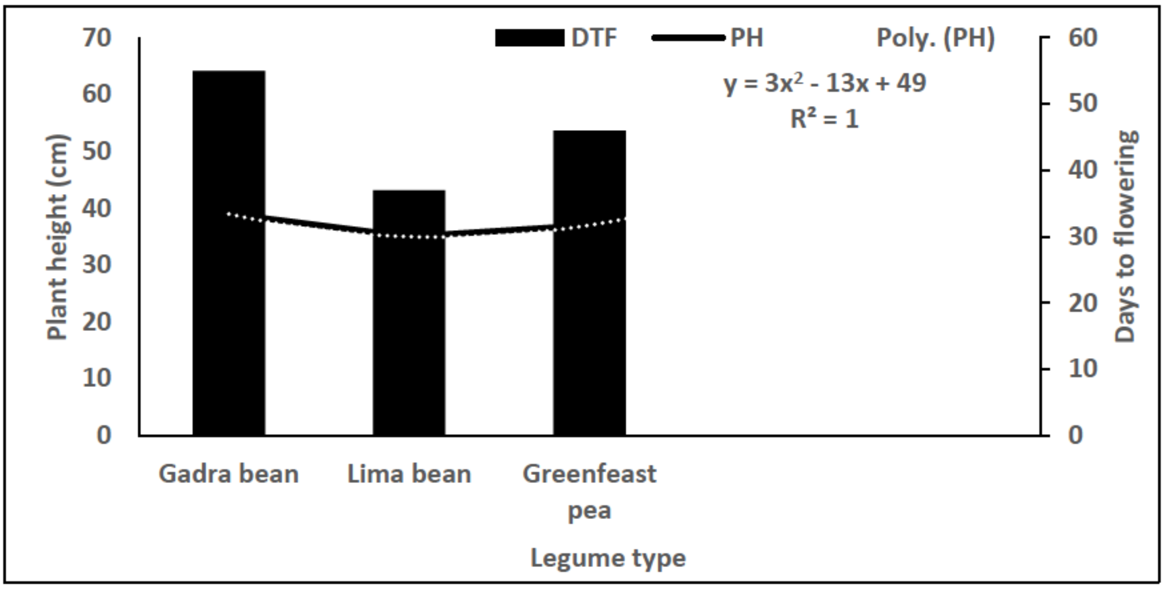


Figure 14 Correlation of plant size and days to flowering as influenced by legume type.

Figure 15 shows that time to flowering (growth) and plant height (growth index), in response to reduction in water stress, are highly correlated ($R^2 = 0.99$).

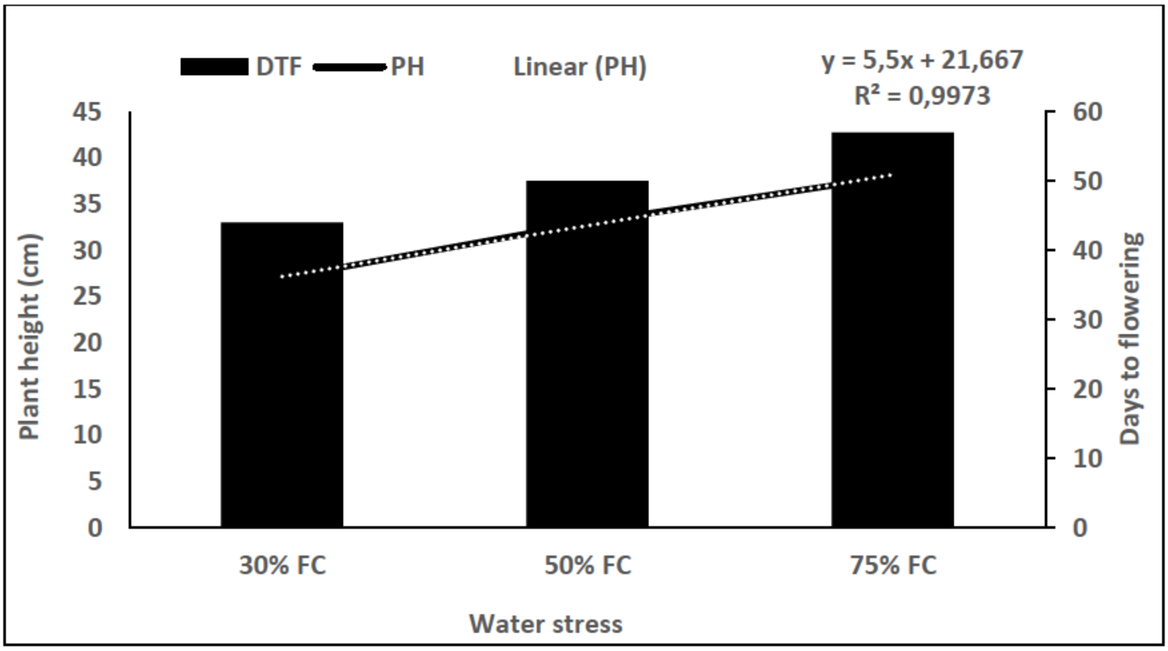


Figure 15 Correlation of plant size (height) with time to flowering in response to water stress.

Plant height was also significantly affected by field capacity × legume different cultivar × study site ($P<0.05$). As water stress levels increased from 75% to 30%, the height of cultivars decreased. This was related to the growth habit of this cultivar; however, water stress depressed plant height of all cultivars and the shortest plants were produced at higher water stress levels (30%). This finding agrees with the results of (Emam et al., 2012) and (Nielsen & Nelson, 1998) who reported on depression of plant height as a result of severe influence from environmental factors such as water stress. In this study, the number of leaves was also significantly affected by field capacity × legume different cultivar × study site ($P<0.05$). As field capacity decreases, the number of leaves also decreases. Gadra bean, lima bean and peas under severe water stress showed fewer leaves, which dropped easily and quickly after senescence. The cells in the leaves lose their rigidity and the leaves probably did not get enough water for physiological functioning.

Figure 16 shows that on a linear basis, yield (grain mass) and time to flowering (growth) are highly correlated ($R^2 = 0.72$), irrespective of soil types.

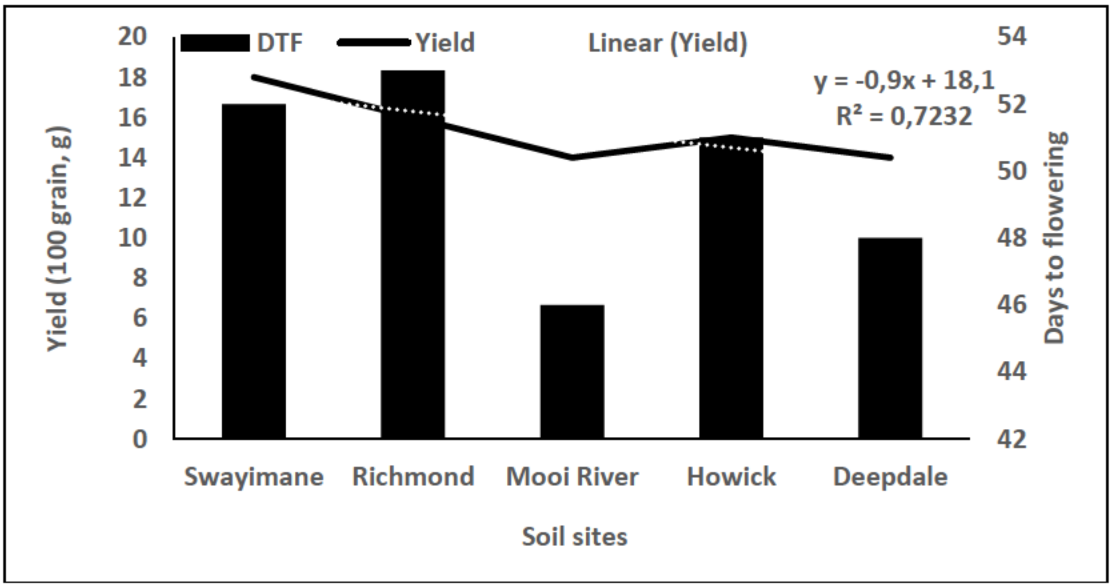


Figure 16 Correlation of legume yield and time to flowering in response to soil type (soil site)

Figure 17 shows that on a linear basis, yield (grain mass) and time to flowering (growth) are highly correlated ($R^2 = 0.25$) across all legume types.

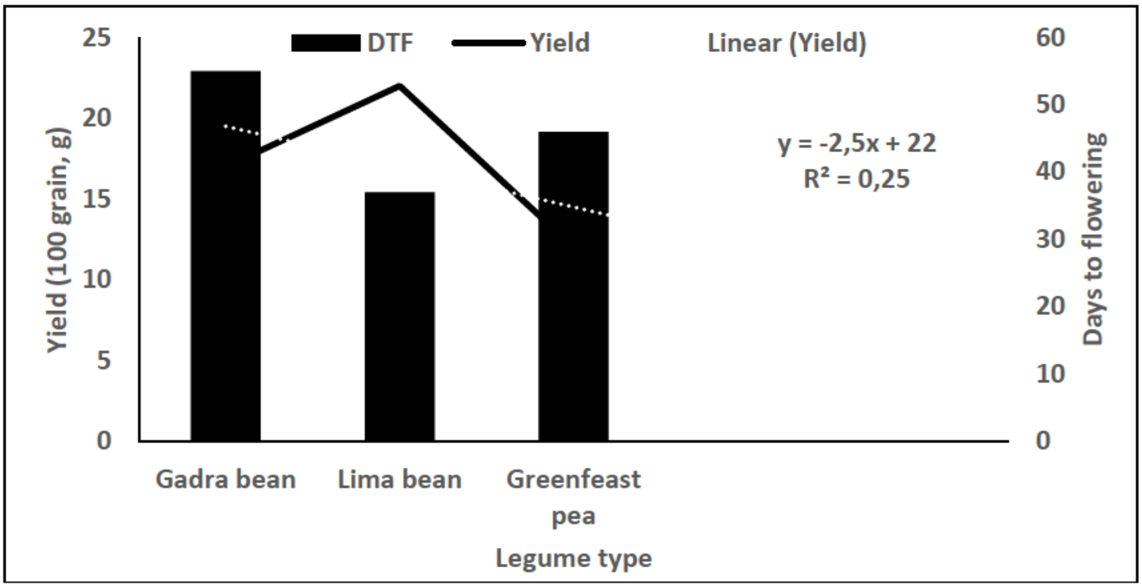


Figure 17 Correlation of legume grain yield with time to flowering as affected by legume type.

Figure 18 shows that when water stress is mitigated, there is a high correlation between growth (time to flower) and yield ($R^2 = 0.99$).

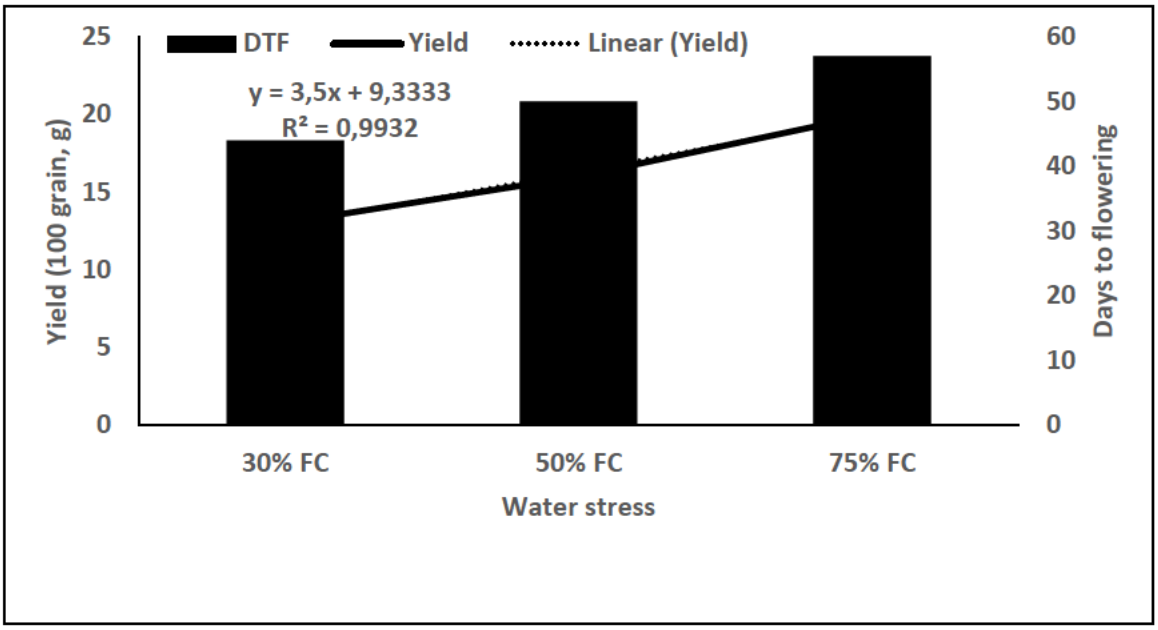


Figure 18 Correlation of legume grain yield with time to flowering in response to water stress.

Determination of stomatal conductance and chlorophyll content index 50 days after planting showed that there were significant differences ($P<0.05$) between the main factors and their interactions (Figures and 19 and 20). Crop response with respect to both performance indices was generally the same. There was a slight decrease in stomatal conductance as the water stress increases. Greenfeast had slightly higher stomatal conductance compared to Gadra and lima beans (Greenfeast peas> Gadra bean > Lima bean). Different sites (soils) affected crop stomatal conductance differently. However, this difference was more associated with water stress levels, suggesting that the soils used in this study had structural and chemical characteristics that influence crop physiological response for photosynthesis.

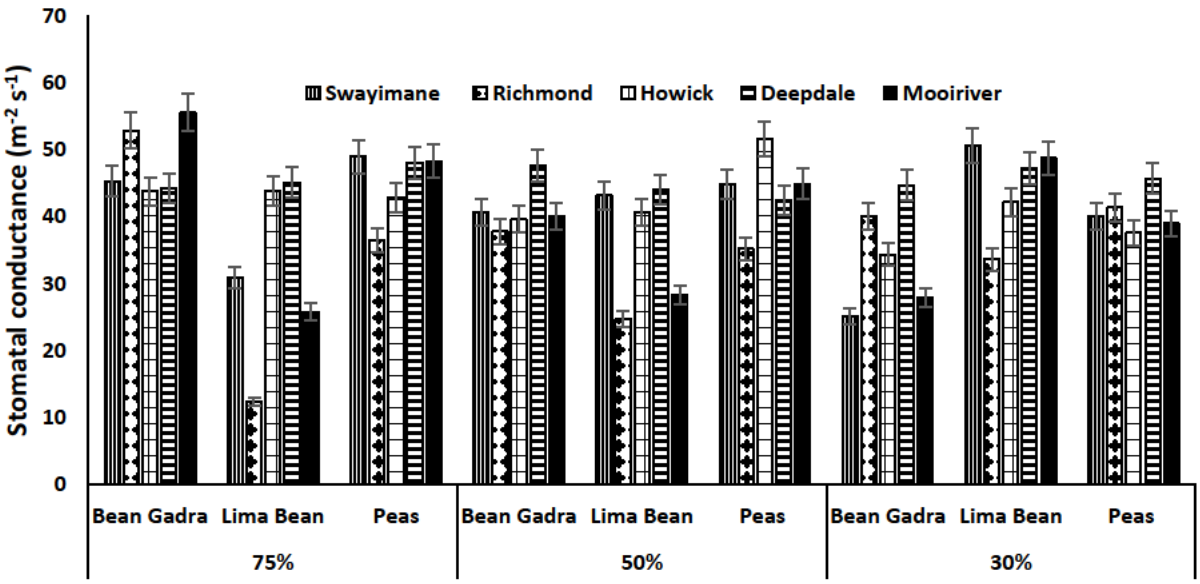


Figure 19. Stomal conductance of three legume types (Gadra bean, Lima bean and Peas) grown in soils from different sites (Swayimane, Richmond, Howick, Deepdale and Mooi river) in response to different levels of water stress water-stress (75%FC, 50%FC, 30%FC).

An interaction of variety x field capacity x legume different cultivar had a significant affect ($P< 0.05$) on chlorophyll content (CCI). As water stress increases from 75% to 30%, the chlorophyll content index decreases. The highest chlorophyll content index was observed in peas in all different field capacities

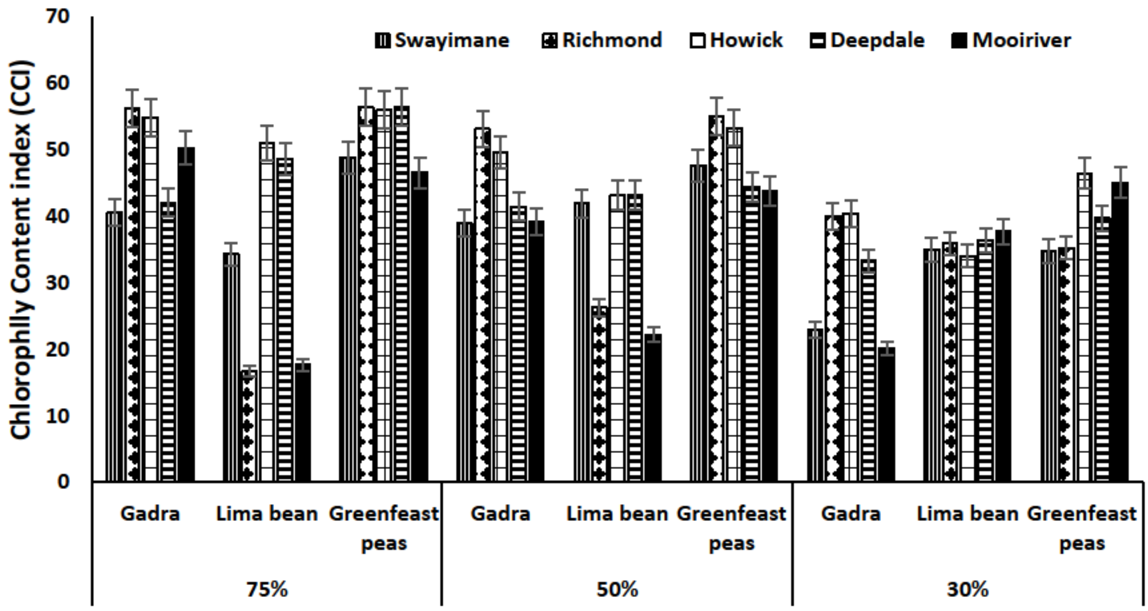


Figure 20 Chlorophyll content index of three legume types (Gadra bean, Lima bean and Peas) grown in soils from different sites (Swayimane, Richmond, Howick, Deepdale and Mooi river) in response to different levels of water stress water-stress (75%FC, 50%FC, 30%FC).

In this study an interaction of crop x field capacity x soil type was significant effect (P< 0.05) for chlorophyll content (CCI). As water stress increases from 75% to 30%, the chlorophyll content index decreases. The reduction in chlorophyll content might have resulted from leaves being damaged and turning yellowish due to drought stress. A decrease in chlorophyll content due to drought stress has been reported in wheat (Talebi, 2011), chickpea (Mafakheri et al., 2010) and dry bean (Mathobo et al., 2017).

There were significant differences (P<0.05) observed for stomatal conductance for crop x field capacity x legume. There was a slightly decrease in stomatal conductance as the water stress increases. Stomatal closure in response to drought stress primarily results in decrease in the photosynthesis rate. The results of Mutava et al. (2015) revealed that under drought stress, stomatal conductance of soybean is responsible for reduced photosynthetic rate. It disrupts photosynthetic pigments and reduces the gas exchange leading to reduction in plant growth and productivity (Anjum et al., 2011).

A full view of crop performance with respect to growth and development, in response to soil and aerial environmental effects can be seen in the context of total plant mass. Comparison of grain mass, above ground plant mass and root mass at harvest maturity was necessary in this study. Results showed that the response of legumes to water stress and soil type, with respect to growth performance indices (time to flowering and rate of plant size shown in Figures 15 to 20) is consistent (Figures 21 to 23).

Figure 21 shows the mean average of plant mass (g) including root mass and grain mass in three legumes types. Lima bean had higher grain mass (22g) and higher root mass (14g) which resulted into high total mass of a plant (33g). However, greenfeast pea was the lowest with total plant mass of 24g.

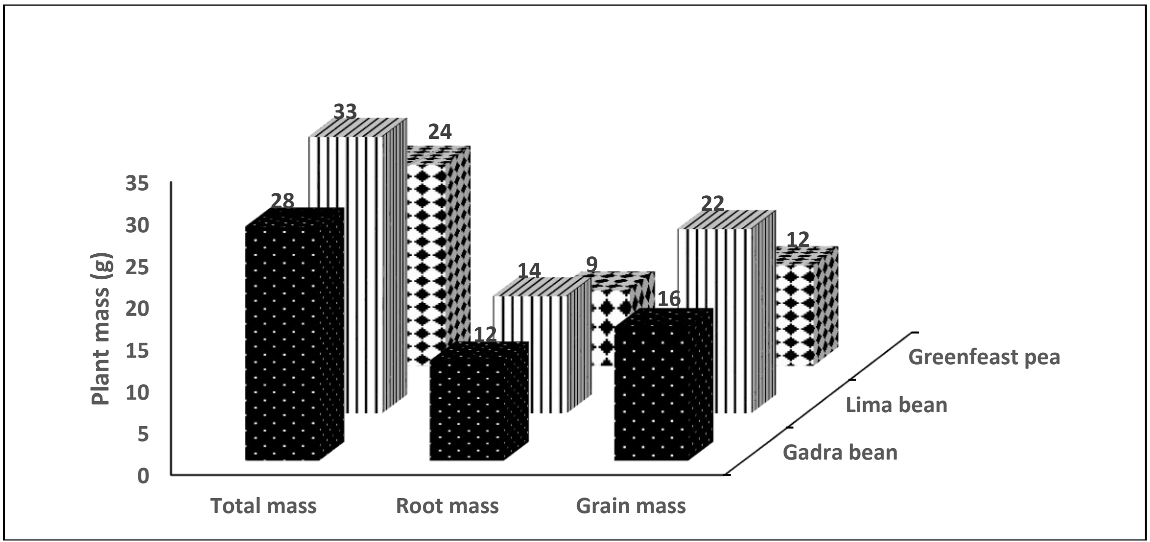


Figure 21 Mean harvest plant mass of three legume types grown in five soil types under three water stress levels.

Figure 22 shows the mean average of plant mass (g) including root mass and grain mass at different sites (soil type). Swayimane and Richmond had higher grain mass (17g and 16g respectively) and higher root mass (11g and 9g respectively) which resulted into high total mass of a plant (30g and 27g respectively). However, Deepdale was the lowest with total plant mass of 21g.

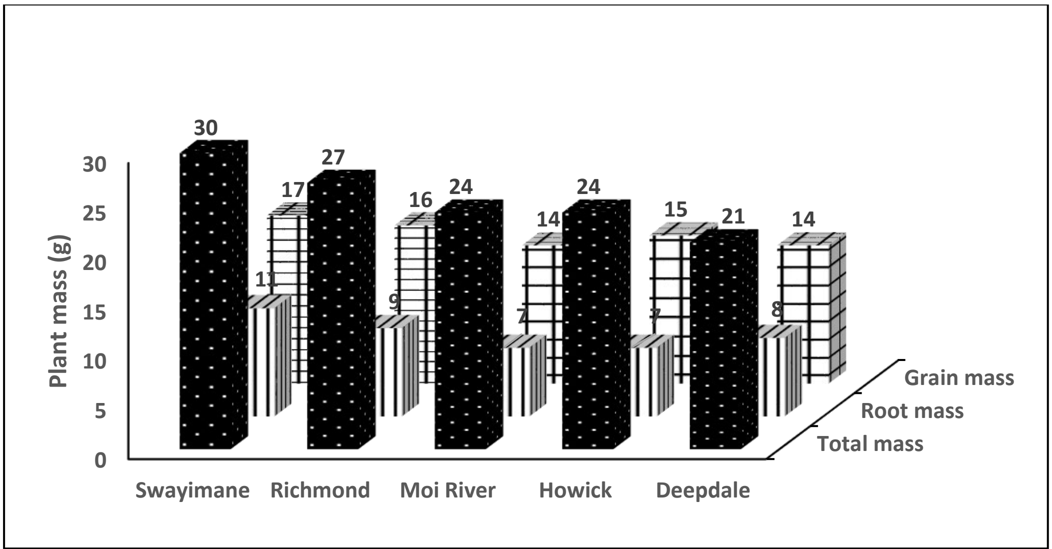


Figure 22 Mean harvest mass of three legume types affected by site soil type (x-axis).

Figure 23 shows the mean average of plant mass (g) including root mass and grain mass in three different field capacity (75%, 50% and 30%). 75%FC had higher grain mass (22g) and higher root mass (12g) which resulted into high total mass of a plant (36g). However, 30%FC was the lowest with total plant mass of 19g. An increase in water stress decreases plant mass.

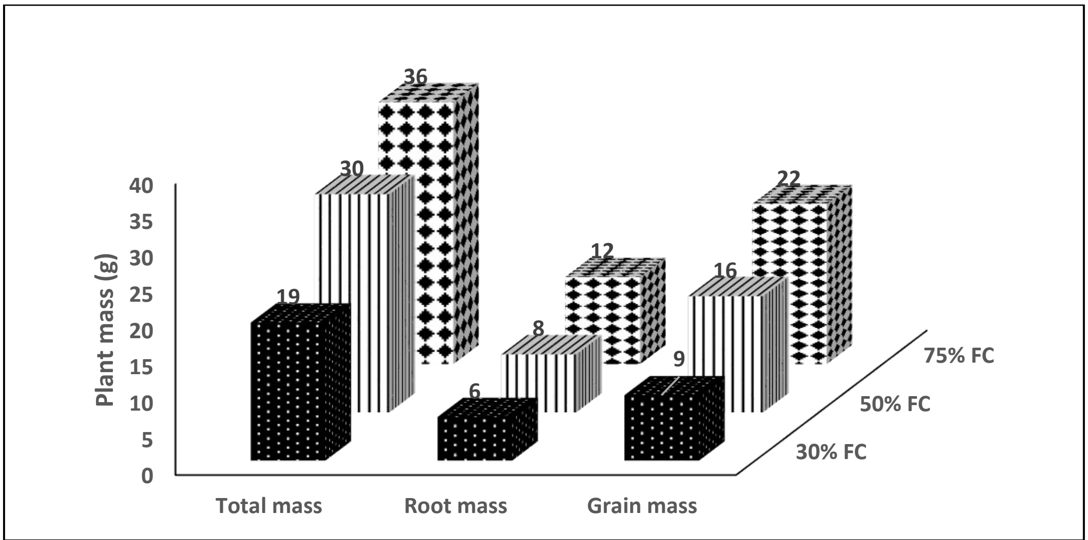


Figure 23 Mean harvest mass of three legume types affected by water stress levels.

It was also observed that the harvest index can be used to confirm the significant differences between legume types as they responded to the effects of water stress in different soil types (Figures 24 to 26).

Figure 24 shows that legume type had significant effect (P=0.05) on harvest index. Lima bean had higher harvest index (67%) when compared with gadra bean (57%) and greenfeast pea (50%)

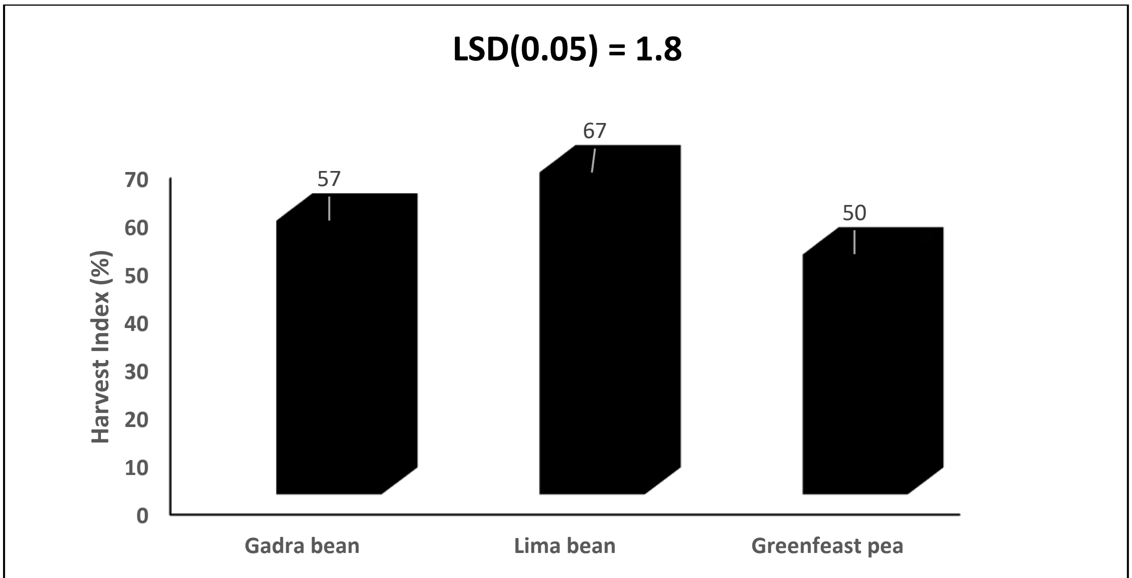


Figure 24 Mean harvest index of three legume types grown in five different soil types in response to three levels of water stress under controlled environment conditions.

Figure 25 shows that soil type had significant effect (P=0.05) on harvest index. Deepdale and Howick had higher harvest index (67% and 63% respectively) when compared with Swayimane (57%), Richmond (59%) and Moi River (58%).

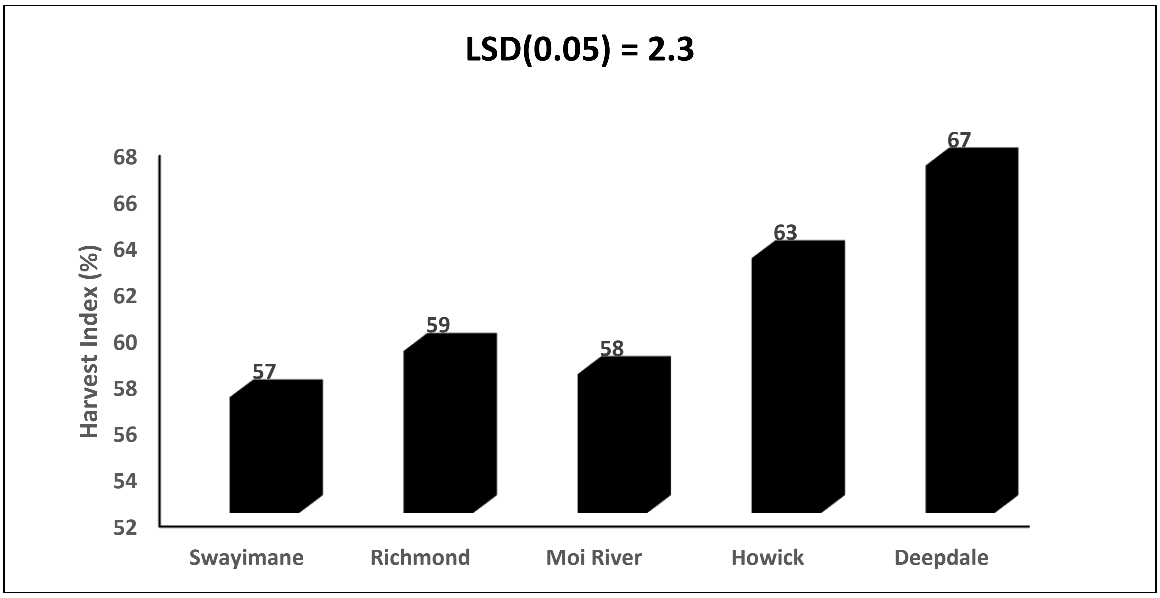


Figure 25 Mean harvest index of three legume types as affected by soil type (site) (x-axis).

Figure 26 shows that legume type had significant effect (P=0.05) on harvest index. As water stress increases from 75% to 30% harvest index decreases, 75% FC (61%), 50% FC (53%) and 30% FC (47%).

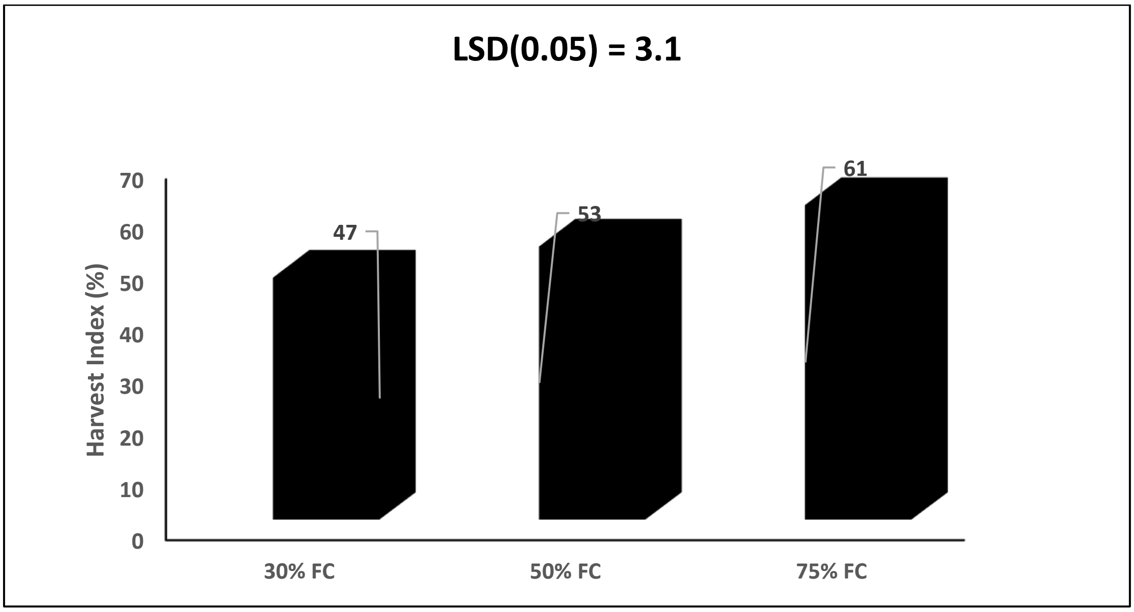


Figure 26 Mean harvest index of three legume types as affected by water stress (x-axis).

4.2 Post-cultivation and harvest determinations

Due to insufficient food intake and poor nourishment, the diet of many South African is imbalanced, it lacks important vitamins, minerals and mostly protein (Hlanga, 2017). This is believed to further deteriorate with the projected climate change, which predicts hotter and drier conditions with more erratic rainfall events (Muller, 2015). This storage of essential nutrients has led to many diseases such as low blood pressure, heart rate and liver problems (Munro, 2012). Legumes are known to be a significant source of proteins, however, to have access to improved agricultural resources such as water, seed quality and suitable soil fertilizers have been observed to be a limiting factor to productivity in many countries. Plant growth sensitivity to water stress is a very different phenomenon and depends on virous factors including the growth stage of the plant, genetic potential, duration and severity of stress (Hlanga, 2017; Zhu, 2002). It also affects leaf development, seed number which ends up reducing the yield of the plant.

Several studies have shown that water deficits imposed during the reproductive development of legumes can decrease the number of flowers, pod and number of seed per pod (Emam et al., 2010, 2012; Mathobo et al., 2017; Nuñez Barrios et al., 2005). Exposure of legumes to drought affect the total biomass and seed yield, photosynthate translocation and partitioning, number of pods and seed per plant, root length and mass, and maturation time (Darkwa et al., 2016). Legumes are very different in their capacity to resist drought because of their interaction with N-fixing (i.e. rhizobia) bacteria and arbuscular mycorrhiza. Although some studies have suggested that N -fixation might be inhibited by water deficit, numerous lines of evidence have shown that genetic variation exists among species and that may be responsible for their variable resistance of water stress (Daryanto et al., 2015). Drought conditions disturb plant morphology, physiology and growing period, whereas moisture content plays a critical role in enzyme activation during germination which could help elucidate the sensitivity of plants to drought at germination stage.

The availability of calcium (Ca), potassium (K), phosphorus (P), and magnesium (Mg) to a legume plant relies upon its concentration in the soil solution and on chemical soil properties, for example, acidity and aluminium concentration (Domingues et al., 2016). Among the mineral supplements, nitrogen (N) is commonly required in the biggest amount by plants, trailed by potassium (K), phosphorus (P), calcium (Ca) and magnesium (Mg) (Tränkner et al., 2018). These minerals are considered as particularly desirable for successful crop growth. If they are missing or inappropriately adjusted, normal development does not occur (Adeyeye, 2005). Crops provide nutritional needs of both man and animals. Man, in turn also consumes the animals. The significant components fundamental for man are additionally basic for creatures. This work consequently gives corresponded information on the degrees of four components (Mg, K, Na and Ca) in the plant organs or parts (buds, flowers, fruits, seeds, leaves, stems, root, cobs, styles, grains, etc.) (Adeyeye, 2005). Phosphorus is an essential supplement fundamental for plant growth and advancement and significant for regulation of different enzymatic activities and constituent for vitality change. Potassium and magnesium are fundamental mineral plant supplements that basically contribute to the process of photosynthesis and the subsequent long-distance transport of photo-assimilates (Schulze et al., 2006). With low calcium availability, a reduction in plant height, leaf area and shoot and root growth will occur (Leal & M, 2008).

Water use efficiency (WUE) is one characteristic significant for plant drought response (Jaleel et al., 2009). Drought stress is an issue since it limits plant production bringing about lower yields which prompt scaled-down food costs and high food costs (Edwards et al., 2012). It happens when accessible water in the soil is decreased and transpiration keeps on losing water without additional water by rain or irrigation. Drought stress is described by the decrease of water content, diminished leaf water potential and turgor misfortune, closure of stomata and abatement in cell enlargement and development (Mathobo et al., 2017). All growth stages are highly sensitive to water deficit especially germination and reproduction stages. Legume crop are commonly grown in rainfed region and different models (Global Climate Model) have predicted increase in the frequency and intensity of drought, indicating the threat of water scarcity (Nadeem *et al.*, 2019).

It was important to determine the effect of water stress treatments on soil quality after harvest. Table 9 shows the physical and chemical properties of soil post-cultivation. Nitrogen percentage (N%) increased with an increase of field capacity and Howick had high percentage of nitrogen in the soil. This is an indication that there was no significant leachate of minerals at 75% FC.

Table 9 Some physical and chemical properties of experimental soils after harvest. SG= Swayimane Gadra bean, SL= Swayimane Lima Bean, SP= Swayimane Peas, RG= Richmond Gadra bean, RL=Richmond Lima bean, RP= Richmond Peas, HG= Howick Gadra bean, HL= Howick Lima bean HP= Howick Peas, DG= Deepdale Gadra bean, DL= Deepdale Lima bean, DP= Deepdale Peas, MG= Mooi River Gadra bean, ML= Mooi River Lima bean and MP= Mooi River Peas.

Soil	pH	N (%)	Exchange acidity (cmol/L)	P (mg/L)	K	Ca	Mg	Zn	Mn	Org.C (%)	Clay (%)
SG, (75%)	4,74	0,4	0,06	89	259	874	296	27	9	>6	27
SG, (50%)	4,71	0,34	0,09	87	262	841	261	23,4	10	5,5	27
SG, (30%)	4,7	0,38	0,09	88	239	852	256	21,1	11	>6	28
SL, (75%)	4,06	0,44	1,55	13	177	1112	199	3,8	130	>6	43
SL, (50%)	4,66	0,27	0,11	99	217	844	247	21,6	11	4,5	23
SL, (30%)	4,65	0,33	0,13	109	226	811	234	20,8	12	5,7	30
SP, (75%)	4,74	0,38	0,08	112	299	855	273	22,1	12	>6	29
SP, (50%)	4,65	0,4	0,11	76	273	816	268	19,2	12	>6	28
SP, (30%)	4,64	0,31	0,11	82	233	807	251	18,8	11	5,4	28
RG, (75%)	4,72	0,31	0,12	41	141	873	168	17,8	9	5,4	43
RG, (50%)	4,73	0,33	0,11	43	130	177	133	13	9	5,6	46
RG, (30%)	4,75	0,35	0,12	27	113	132	127	10,2	7	5,6	45
RL, (75%)	4,62	0,37	0,11	100	386	108	170	2,4	18	6	29
RL, (50%)	4,66	0,36	0,11	36	177	121	127	11,3	9	5,9	46
RL, (30%)	4,68	0,36	0,11	45	132	115	120	15,1	11	5,4	45
RP, (75%)	4,02	0,48	1,52	11	181	1040	186	3,7	180	>6	43
RP, (50%)	4,67	0,33	0,11	56	130	1024	151	12,2	11	5,6	46
RP, (30%)	4,65	0,34	0,08	83	171	1018	161	15,1	14	5,6	47
HG, (75%)	4,08	0,44	1,25	12	190	1165	206	3,2	160	>6	42
HG, (50%)	4,03	0,51	1,68	11	173	1123	203	3,2	150	>6	39
HG, (30%)	4,04	0,45	1,53	14	195	1148	209	3,8	130	>6	42
HL, (75%)	4,06	0,46	1,53	13	201	1005	175	3,3	120	>6	44
HL, (50%)	4,05	0,49	1,49	10	176	1153	203	3	160	>6	43
HL, (30%)	4,65	0,36	0,11	47	213	1009	180	11,8	13	5,8	46
HP, (75%)	4,06	0,44	1,37	14	214	1147	202	3,6	160	>6	44
HP, (50%)	4,05	0,41	1,43	10	174	1124	202	2,9	180	>6	45
HP, (30%)	4	0,43	1,77	14	203	993	204	3,5	160	>6	45

MG, (75%)	4,86	0,11	0,09	7	379	1002	406	2,8	33	2,3	36
MG, (50%)	4,75	0,12	0,08	6	324	895	453	1,6	35	2,5	38
MG, (30%)	4,83	0,12	0,08	4	270	976	470	1,3	27	2,5	40
ML, (75%)	4,86	0,12	0,11	8	406	1005	495	3	52	2,1	41
ML, (50%)	4,87	0,11	0,05	8	428	1002	450	2,7	56	2,2	40
ML, (30%)	4,71	0,11	0,05	3	241	955	452	2	34	2,3	39
MP, (75%)	4,98	0,14	0,07	11	372	907	446	3	45	2,7	40
MP, (50%)	4,97	0,1	0,06	10	372	949	461	1,8	42	1,9	41
MP, (30%)	4,82	0,15	0,06	14	353	916	447	1,8	42	2,5	41
DG, (75%)	4,27	0,22	0,86	12	76	376	279	0,6	18	3,4	54
DG, (50%)	4,27	0,24	0,81	4	58	358	266	0,2	15	3,4	53
DG, (30%)	4,26	0,19	0,77	12	72	381	271	1,1	15	3,3	50
DL, (75%)	4,29	0,19	0,74	6	74	374	267	0,4	15	3	49
DL, (50%)	4,31	0,22	0,6	4	81	371	263	0,3	16	3,2	51
DL, (30%)	4,24	0,17	0,87	3	53	338	234	0,3	17	3	53
DP, (75%)	4,37	0,22	0,52	5	82	374	256	0,4	18	3,4	51
DP, (50%)	4,33	0,2	0,58	3	77	368	247	0,5	19	3,1	51
DP, (30%)	4,29	0,21	0,72	4	72	388	273	0,3	19	3,3	51

The quality of above ground vegetative plant material is shown in Table 10 below.

Table 10 Chemical properties of experimental plant material after harvest

The interaction among the elements (Ca, K, Mg, Mn, Na and P) with different site, different cultivar and field capacity was significant. The relationship between Fe and different site, different cultivar and field capacity was insignificant.

STUDY SITE	CULTIVAR	FC	ELEMENTS						
			Ca	Fe	K	Mg	Mn	Na	P
Swayimane	Gadra	30	10,05	0,84	24,21	5,23	0,18	0,29	1,00
	Gadra	50	10,46	0,59	28,70	5,64	0,09	0,28	0,40
	Gadra	75	12,47	0,27	26,45	5,23	0,38	0,14	0,64
	Lima	30	12,50	0,82	38,00	6,28	0,19	0,30	1,07
	Lima	50	11,74	0,48	17,99	5,67	0,17	0,17	0,62
	Lima	75	11,40	0,47	18,01	5,78	0,14	0,17	1,37
	Peas	30	8,63	2,34	22,64	7,13	0,21	0,39	0,90
	Peas	50	14,72	0,89	35,09	7,17	0,23	0,42	0,52
	Peas	75	16,08	0,39	25,44	5,91	0,13	0,49	0,74
Richmond	Gadra	30	9,63	0,06	54,78	4,69	0,03	0,14	0,18
	Gadra	50	10,92	0,25	39,46	4,10	0,07	0,18	0,51
	Gadra	75	10,14	0,30	22,64	4,99	0,07	0,16	0,36
	Lima	30	13,62	0,69	18,32	4,40	0,13	0,22	0,81
	Lima	50	15,01	0,49	17,77	5,52	0,14	0,24	0,62
	Lima	75	12,59	0,41	14,21	4,50	0,10	0,21	0,97
	Peas	30	16,53	1,75	17,42	4,99	0,29	0,35	0,63
	Peas	50	19,99	1,13	18,67	5,48	0,15	0,34	0,48
	Peas	75	14,76	0,51	13,72	4,44	0,47	0,35	0,58
Howick	Gadra	30	12,88	0,34	21,34	4,77	0,47	0,20	0,69
	Gadra	50	11,46	0,32	25,62	5,57	0,23	0,21	0,25
	Gadra	75	12,18	0,49	15,68	4,62	0,35	0,21	0,52
	Lima	30	11,78	2,02	18,48	4,45	0,83	0,33	0,85

	Lima	50	11,32	0,42	16,62	4,37	0,66	0,22	0,57
	Lima	75	10,81	0,31	15,38	3,57	0,42	0,23	0,70
	Peas	30	10,65	3,67	15,59	4,10	1,17	0,44	0,99
	Peas	50	15,17	0,32	12,73	4,92	0,61	0,32	0,48
	Peas	75	20,31	0,29	14,39	5,88	0,65	0,45	0,38
Deepdale	Gadra	30	9,88	0,59	11,76	6,15	0,37	0,28	1,25
	Gadra	50	7,85	0,61	15,86	4,23	0,17	0,17	0,81
	Gadra	75	10,28	0,42	27,13	5,43	0,34	0,24	0,45
	Lima	30	9,73	0,47	14,22	5,20	0,19	0,16	1,35
	Lima	50	7,35	0,28	8,73	4,99	0,25	0,25	0,79
	Lima	75	7,19	0,32	8,93	4,07	0,39	0,36	0,82
	Peas	30	9,68	1,87	7,35	5,80	0,30	0,91	1,08
	Peas	50	5,02	0,28	4,80	3,93	0,16	0,54	0,62
	Peas	75	8,48	0,24	8,62	4,98	0,24	0,40	0,58
Mooi River	Gadra	30	16,22	0,94	28,93	6,92	0,30	0,31	0,94
	Gadra	50	15,65	0,30	25,58	5,68	0,15	0,19	0,49
	Gadra	75	11,27	0,27	28,87	5,16	0,21	0,21	0,85
	Lima	30	12,15	0,59	22,29	5,78	0,36	0,24	0,72
	Lima	50	12,88	0,60	23,95	5,64	0,35	0,26	0,72
	Lima	75	11,76	0,31	25,98	6,22	0,32	0,27	0,70
	Peas	30	13,41	1,19	20,47	6,00	0,29	0,59	1,32
	Peas	50	17,03	1,15	17,95	5,88	0,20	0,33	0,41
	Peas	75	15,80	1,04	17,06	5,41	0,19	0,32	1,14
	LSD		**0.555**	**0.926**	**0,058**	**0,213**	**0,180**	**0,089**	**0,115**

The study revealed that increased water stress caused adverse effects on plant growth and development. Also, the concentrations of K^+ and Mg^{2+} were significantly decreased under severe stress treatments. This decrease of Mg^{2+} and K^+ is also agrees with a decrease of chlorophyll content index, this was stated by Adeyeye, 2005 that Magnesium and Potassium are a constituent of every chlorophyll molecule, and therefore essential for photosynthesis, green plants cannot do without it. Based on the experiment potassium (K^+) and magnesium (Mg^{2+}) decreases with an increase of water stress in all cultivars and in different sites except in Swayimane Mg^{2+} was high in 50% of gadra bean and peas and also in Richmond lima bean and peas are high in Mg^{2+} in 50%. Ca $^{2+}$, P, and Mn^{2+} content increased with an increase of water stress. A high calcium, phosphorus and manganese concentrations in the nutrient solution showed an increase in the dry mass of the leaf and plant dry. Sodium is not said to be universally essential in plant growth, but its soluble compounds may increase crop growth. It has been known for many years that this element will in part replace potassium and that common salt will at times increase crop yield (Clauw et al., 2015).

5. CONCLUSION AND RECOMMENDATIONS

The study showed that in general the different types of legumes respond to water stress the same way. This was indicated by the pattern of suppression of growth rate and plant size which was the same for all legume types. The final plant mass and yield also showed the same pattern. Increasing water stress by reducing field capacity has a quick effect of reducing plant performance. This was confirmed by the highly significant differences between water stress treatments with respect to all growth and yield variables measured. It was interesting to note that when the three plant parts, above ground vegetative plant mass, root mass and grain yield, it was root mass that was most sensitive to water stress, followed by grain yield. This finding suggests that water stress affects crop performance mainly by reducing the capacity of root growth. Thus, the transfer of water and nutrients to the plant parts responsible for physiological performance, e.g. photosynthesis, is also limited. Consequently, crop yield is reduced. This effect was clearly evident in the context of chlorophyll content index and stomatal conductance, respectively.

Soil type has a direct relationship to the capacity of soil to perform under water stress. This was shown particularly with respect to significant interactions between soil type and crop type when growth and yield indices were measured. The reduction of field capacity from 75% to 30% resulted in low yields of all legume varieties in respect of all soil types. Significant differences in the concentration of calcium, magnesium, iron, phosphorus, manganese, sodium and potassium in plant tissue (except for iron), were observed. There was no significant difference in iron as water stress increases. This suggests that while drought stress can reduce plant chemical quality, iron may be more resistant to react to this effect.

There are a number of recommendations for future research, as observed in this study, some as a result of study limitations. These can be summarised as follows:

1. There was no adequate historical evidence to justify the choice of different types of legumes, other than growth habit and other morphological characteristics, including seed size and shape. An investigation into the physiology and biochemistry of legume species with respect to water use efficiency will be needed.
2. Grains are the major repository of nutrients during crop ripening phases, and thus a detailed analysis of seed quality and chemical composition is likely to produce results that link crop response to water stress more accurately. This would be important in the context of genetic improvement and testing under climate change.

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