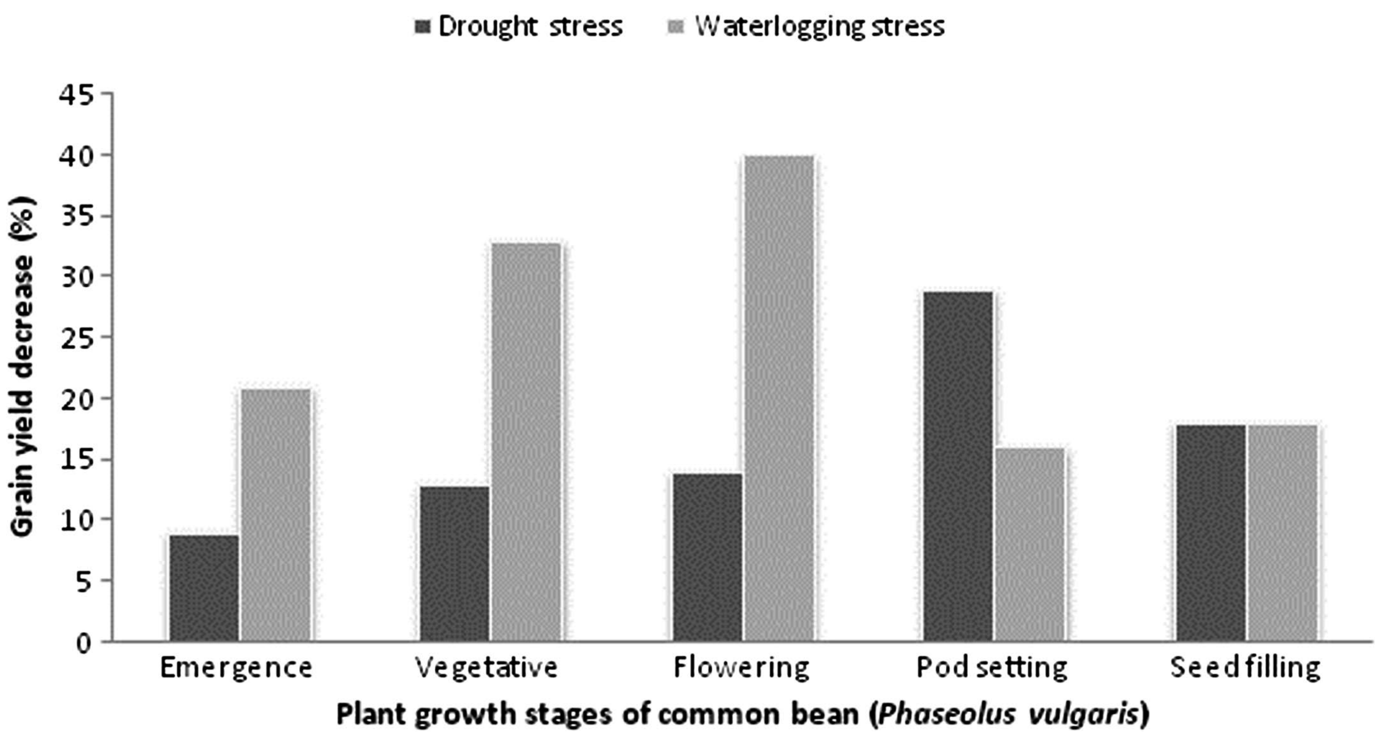
cogent food & agriculture



SOIL & CROP SCIENCES | RESEARCH ARTICLE

Effect of excessive and minimal soil moisture stress on agronomic performance of bush and climbing bean (*Phaseolus vulgaris* L.)

Nepomuscene Ntukamazina, Richard N. Onwonga, Rolf Sommer, Clare M. Mukankusi, John Mburu and Jean Claude Rubyogo

Cogent Food & Agriculture (2017), 3: 1373414 cogent food & agriculture

SOIL & CROP SCIENCES | RESEARCH ARTICLE

Effect of excessive and minimal soil moisture stress on agronomic performance of bush and climbing bean (*Phaseolus vulgaris* L.)

Nepomuscene Ntukamazina[1*], Richard N. Onwonga[1], Rolf Sommer[2], Clare M. Mukankusi[2], John Mburu[3] and Jean Claude Rubyogo[2]

Received: 05 June 2017
Accepted: 24 August 2017
First Published: 31 August 2017

*Corresponding author: Nepomuscene Ntukamazina, Department of Land Resource Management and Agricultural Technology, University of Nairobi, Nairobi, Kenya
E-mail: ndabanepo@gmail.com

Reviewing editor:
Manuel Tejada Moral, University of Seville, Spain

Additional information is available at the end of the article

Abstract: Water stress is a major crop production constraint for common bean (*Phaseolus vulgaris* L). The response of bush and climbing bean to excessive and minimal soil moisture at various plant growth stages was investigated under greenhouse for two growing periods; September–February 2016 and March–July 2016. The control consisted in watering with recommended rates for each plant growth stage. Two bean genotypes RWR2245 (bush bean) and MAC44 (climbing bean) were used for this study. The minimal soil moisture (drought stress) treatment consisted of withholding water supply, from the on-set of emergence, vegetative, flowering, pod setting and seed filling growth stages, up to the wilting point of plants. The excessive soil moisture (waterlogging stress) was achieved by saturating the soil on a daily basis for five successive days, starting from the on-set of the aforementioned plant growth stages. For each genotype, these treatments were replicated four times and arranged in a Completely Randomized Design. Drought stress accelerated

ABOUT THE AUTHORS

Nepomuscene Ntukamazina is a PhD student at the University of Nairobi. His research interest is on evaluating effects of weather stresses on yield of common bean to inform improvement of index-based insurance models for beans.

Richard N. Onwonga is a senior lecturer in the Department of Land Resource Management and Agricultural Technology at the University of Nairobi. He specializes in soil agroecology with current research interests in application of agroecological intensification approaches to enhance agricultural productivity.

Rolf Sommer is a senior scientist at the International Center for Tropical Agriculture; working in the field of soil health/fertility, soil nutrition and crop modelling.

Clare M. Mukankusi is a senior scientist and bean breeder at the International Center for Tropical Agriculture.

John Mburu is a senior lecturer and chairman of the Department of Agricultural and Applied Economics at the University of Nairobi.

Jean Claude Rubyogo is a senior scientist and seed systems specialist at the International Center for Tropical Agriculture; Coordinating the East and Central Africa Bean Research Network.

PUBLIC INTEREST STATEMENT

Common bean (*Phaseolus vulgaris*) is a good source of protein, vitamins and minerals. Increased intake of beans provides nutritional benefits to the diet, and may help to reduce malnutrition status in rural communities. Water stress (drought stress and waterlogging) is among key limiting factors for common bean production. This study was initiated to understand the effect of weather related stresses at different plant growth stages on yield of dry beans. From the study findings, drought stress accelerated the number of days to maturity whilst waterlogging stress increased the number of days to maturity. Both water related stress at vegetative, flowering and pod setting highly decrease bean production with pod setting and flowering being the most sensitive stages to drought stress and waterlogging stress, respectively. These results will provide scientific basis for designing management strategies to mitigate environmental production constraints and optimize bean yield production.

the number of days to maturity whilst waterlogging stress tended to increase the number of days to maturity. Both stresses reduced the agronomic performance of both genotypes. However, pod setting and flowering were the most sensitive stages to drought stress and waterlogging stress, respectively.

Subjects: Environment & Agriculture; Agriculture & Environmental Sciences; Agriculture; Crop Science

Keywords: crop development; drought stress; grain yield; *Phaseolus vulgaris* L; waterlogging

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume and staple food in East Africa. For instance in Burundi, Rwanda, Uganda and in Western Kenya, bean consumption is estimated at 60 kg per capita per year i.e. thrice the mean for Africa (Beebe, Rao, Blair, & Acosta-Gallegos, 2013; Buruchara et al., 2011; Ostyula, 2010). However, due to various production constraints, availability and cost often limit bean consumption.

Nutritionally, common bean has a high protein content with a good source of energy and it provides folic acid, dietary fibre and complex carbohydrates (Dagnew, Haileselassie, & Feyissa, 2014). In addition, common bean protein is high in lysine, which on the other hand is relatively deficient in maize, cassava and rice, making it a good dietary complement to these staples (Katungi, Farrow, Chianu, Sperling, & Beebe, 2009). Given that most proteins consumed by the poor are from plant sources, common bean plays a significant role in alleviating malnutrition. Bean products are consumed at various stages of plant development, and thus, offer a staggered and prolonged food supply in the form of leaves, green pods, fresh grains, dry grains, as well as bean composite flour for porridge and other snacks.

Beyond promoting food, health and nutritional security, common bean provides a steady and lucrative source of income for many rural households, with the value of bean sales exceeding US $ 500 million annually (Food and Agriculture Organization, 2011; Kalima, 2013). In Zambia for instance, common bean is one of the major sources of income for the smallholders especially women (Chalwe, Mwiinga, & Tembo, 2011; Samboko, 2011).

Despite the importance of common bean in food security and nutrition, production of the crop is limited due to biotic and abiotic stresses (Dagnew et al., 2014). In most countries, the bean crop is grown by smallholder farmers under rain fed conditions and increasingly subjected to unreliable dry and/or wet weather conditions. Therefore, water stress is a very common problem during the growing period often aggravated by the declining soil fertility, diseases, limited access to improved seeds and suboptimal agronomic practices (Calvache, Reichardt, Bacchp, & Dourado-Neto, 1997; Polania, Poschenrieder, Beebe, & Rao, 2016).

On one hand, drought is a major constraint to bean production and its mode of action is highly complex and variable in response, accentuated by interacting factors and localized within environmental regions (Dagnew et al., 2014; Munyasa, Chemining'wa, Kimani, Mburu, & Nderitu, 2013). According to Polania et al. (2016) drought is the second most important factor in yield reduction after diseases. Brief periods of water shortage impose a stressful metabolic situation by particularly altering plant photosynthesis, which leads to a depletion of energy and sugars and negatively affect both quality and yield of beans (Cuellar-Ortiz, Arrieta-Montiel, Acosta-Gallegos, & Covartubias, 2008). Adaptation to drought stress encompasses morphological, physiological, and biochemical mechanisms, including a deeper root system, stomatal control, and improved photosynthate remobilization under stress (Beebe et al., 2011).

On the other hand, excessive rainfall often exposes plants to transient or permanent waterlogging stress, particularly in tropical and subtropical regions. In waterlogged soils, gas exchange between root systems and soil pore spaces are limited due to oxygen diffusion resistance that is around 10,000 times higher in water than in the air (Ashraf, 2012; Borella, Do Amarante, De Oliveira, De Oliveira, & Braga, 2014). Since oxygen diffuses through undisturbed water much more slowly than a well-drained soil, when soils are saturated, oxygen requirements rapidly exceed available concentrations (Meronuck, Wright, & Rehm, 2016). As a result, plant roots suffer from hypoxia (deficiency of O_2) or anoxia (absence of O_2), which reduce nutrient uptake, crop growth and yield (Ashraf, 2012; Houk, Frasier, & Schuck, 2004). Crop damages due to waterlogging include necrosis, stunting, defoliation, reduced nitrogen fixation and plant death (Ahmed et al., 2013).

In addition to the effect on the roots, excessive rainfall does have destructive effects on plant leaves. A number of foliar diseases such as common bacterial blight, halo blight, angular leaf spot and bean anthracnose are prominent in periods of wet weather resulting in loss in photosynthetic area which can affect final yield (Buruchara, Mukankusi, Ampofo, & Walker, 2010; Cyamweshi et al., 2013; Mukankusi, Melis, Derera, Laing, & Buruchara, 2008). Only 2 days of flooding at vegetative stage can cause 18% of yield loss while it may exceed to 26% if flooding occurs at early reproductive stage of soybean (Ahmed et al., 2013). As indicated by Beebe et al. (2011) and Li, You, Colmer, and Barbetti (2015) in common bean, no variety to date has been identified with resistance to waterlogging. However, farmers in Uganda and Rwanda substitute bush bean genotypes with climbing beans while coping with waterlogging stress (Cyamweshi et al., 2013).

Although many studies have been carried out on the effect of water stress, mostly drought conditions, at particular stages of bean crop development, few studies are related to assessment of excessive moisture stress at various developmental stages of the common bean. The main objective of this study was therefore to determine the most sensitive stages of bean growth to water stresses and their impact on yield of two common bean genotypes (MAC44 and RWR2245) with different growth habits that were grown under greenhouse conditions. These two genotypes are regionally recognized for their high yield potential and have been recently released as varieties in Rwanda (2013), Burundi (2015), and pre-released in Kenya. They are recommended for low and medium altitudes and have yield potentials of 2.5 t ha^{-1} for RWR2245 and of 3.5 t ha^{-1} for MAC44. Because of their high yield potential, farmers have rapidly adopted these varieties as grain yield is the most desired character of farmer's interest in field crops and considered as the economic outcome of farming (Ahmed, Selim, Alderfasi, & Afzal, 2015). Particularly, in Rwanda and Burundi, where climbing bean varieties are being intensively adopted, MAC44 has appeared as an alternative solution to bean production under scarcity of arable land (Katungi et al., 2009).

The expected outcome from this study is that the information generated would contribute to develop possible agronomic and insurance packages to confront variations in rainfall and sustain bean production that are beneficial to smallholder farmers, particularly in developing countries.

2. Materials and methods

2.1. Location and plant materials

The study was conducted under greenhouse conditions (greenhouse) for two growing periods: September–February 2016 and March–July 2016. The first growing period was carried out in Kenya at Kabete Field Station of the University of Nairobi (elevation: 1,850 masl) and the second in Rwanda at Rubona Research Station (elevation: 1,650 masl) of Rwanda Agriculture Board (RAB).

In order to assess the effect of water stresses on the performance of both bush and climbing beans, two improved bean genotypes namely MAC44 (climbing bean) and RWR2245 (bush bean) were used. Major characteristics of the two genotypes selected for the study are listed in Table 1.

Table 1. Major characteristics of the two genotypes selected for the study

Attributes	MAC44	RWR2245
Growth habit	Climbing (type IV)	Bush (type I)
Adaptation zone	Low and medium altitude	Low and medium altitude
Days to maturity	87	78
Potential yield, kg ha^{-1}	3,500	2,500
Iron content, mg kg^{-1}	78	75
Zinc content, mg kg^{-1}	29	29.8
Seed size	Large	Medium
Color	Red mottled	Red mottled
Disease, tolerance/resistance	Angular leaf spot, Ascochyta, Root rot, Anthracnose, Bean common mosaic virus	Angular leaf spot, Ascochyta, Root rot, Anthracnose, Bean common mosaic virus

Source: Adapted from Musoni et al. (2012).

2.2. Experimental design and treatments

The evaluated treatments were three watering regimes: minimal/moderate watering (drought stress), excessive watering (waterlogging stress) and normal watering (control), applied at the on-set of the four plant growth stages i.e. emergence, vegetative, flowering, pod setting and seed filling. These treatments were initiated at the two primary leaves unfolded for emergence stage, the fourth trifoliate leaf unfolded for vegetative stage, at one open flower for flowering, at early pod set for pod setting and at early seed fill for seed filling stage. Each treatment was replicated four times and pots were arranged in a Completely Randomized Design (CRD). The combination of these soil moisture levels with plant growth stages resulted in eleven treatments (Table 2).

Table 2. Description of treatments

Growth stages	Soil moisture stresses	Treatments	Treatment description
Emergence	Drought stress	DS-E	Stop watering from the two primary leaves unfolded (VC) until the plants wilt
	Waterlogging stress	WL-E	Keep soil water content at saturation for five successive days from the two primary leaves unfolded
Vegetative	Drought stress	DS-V	Stop watering from the 4th trifoliate leaf unfolded (V4) until the plants wilt
	Waterlogging stress	WL-V	Keep soil water content at saturation for five successive days from the 4th trifoliate leaf unfolded
Flowering	Drought stress	DS-F	Stop watering from early flower stage (R1) until the plants wilt
	Waterlogging stress	WL-F	Keep soil water content at saturation for five successive days from early flower stage
Pod setting	Drought stress	DS-P	Stop watering from early pod set (R3) until the plants wilt
	Waterlogging stress	WL-P	Keep soil water content at saturation for five successive days from early pod set stage
Seed filling	Drought stress	DS-S	Stop watering from early seed fill (R5) until the plants wilt
	Waterlogging stress	WL-S	Keep soil water content at saturation for five successive days
Throughout all the plant growth stages	Normal watering	Control	Watering with recommended rates of 2, 3, 6, 7, and 7 mm day^{-1} at emergence, vegetative, flowering, pod development and seed filling, respectively (Beebe et al., 2013; Meronuck et al., 2016)

The drought stress treatment consisted of withholding water supply until the plant reaches wilting. The treatment was initiated at the two primary leaves (unifoliolate) unfolded for emergence stage, at the fourth trifoliate leaf unfolded (V4) for vegetative stage, at one open flower (R1) for flowering stage, at early pod set (R3) for pod setting stage and at early seed fill (R5) for seed filling stage.

The control treatment was applied by watering each pot with an equivalent of 2 mm day^{-1} at emergence, 3 mm day^{-1} at vegetative, 6 mm day^{-1} at flowering, 7 mm day^{-1} at pod setting and 7 mm day^{-1}at seed filling, as recommended by Beebe et al. (2013) and Meronuck et al. (2016). Waterlogging stress was applied by always keeping the soil water content above 40 and 35% of volumetric water content for clay and sandy-soil, respectively (Sheppard & Hoyle, 2016). This was achieved by saturating the soil on a daily basis for five successive days, starting from the two primary leaves unfolded for emergence stage, from the fourth trifoliate leaf unfolded (V4) for vegetative stage, from one open flower (R1) for flowering stage, from early pod set (R3) for pod setting stage and from early seed fill (R5) for seed filling stage.

Before and after the water stress treatments were applied, the pots received recommended watering rates based on the plant growth stages. During the late seed filling, watering was stopped as it is known to promote more vegetative growth at the expense of reproductive growth in common bean (Beebe et al., 2013) (Table 3).

Throughout this experiment, water stress treatments were applied by monitoring soil moisture content, using a capacitance probe (ProCheck PC-1 with GS sensor 2007–2014 Decagon Devices).

2.3. Growth conditions and greenhouse management

The experimental unit was a five litre capacity pot filled with 4 kg of top soil. The characteristics (soil texture and fertility status) of the soils used in this experiment were clay (September–February) and sandy-clay (March–July) soils in texture, low P, moderately acidic, moderate in total *N*, very low (September–February) and Medium in Organic Carbon (Apal Agricultural Laboratory, 2016; Horneck, Sullivan, Owen, & Hart, 2011) (Table 4).

Planting was done at seedling rate of two seeds per pot and thinned to one plant per pot after emergence (at two primary leaves unfolded). Each experimental pot was fertilized with a pre-planting dose of Urea (23 kg ha^{-1}) and TSP (46 kg ha^{-1}), in addition to organic manure (10 tha^{-1}). During the experimental period, pots were kept free from weeds, pests and diseases by a combination of hand weeding, use of insecticide (Cypermethrin 5% EC) for insect control and fungicide (Safari-Zeb 80WP) for fungal diseases control.

Table 3. Estimated daily recommended rates for normal irrigation at various plant growth stages

Plant growth stages	Recommended rates		Pot area	Applied rates	
	mm day^{-1}	L m^{-2}	m^2	L pot^{-1}	mL pot^{-1}
Emergence	2	2	0.0314	0.0628	65
Vegetative	3	3		0.0942	100
Flowering	6	6		0.1884	190
Pod development	7	7		0.2198	220
Seed filling	7	7		0.2198	220
Physiological maturity	3	3		0.0942	100
Leaves yellowing	1	1		0.0314	35

Source: Adapted from Meronuck et al. (2016).

Table 4. Physical and some chemical characteristics of experimental soils

Site (season)	Clay (%)	Sand (%)	Silt (%)	pH	Bray P (ppm)	Total *N* (g kg^{-1})	Total *C* (g kg^{-1})
Kabete (2016A)	59	23	18	5.0	1	1.6	18
Rubona (2016B)	36	54	10	5.5	10	1.8	40

Cypermethrin 5% EC and Safari-Zeb 80 WP were sprayed every 7 to 10 days at a rate of rate of 0.05 g L^{-1} of water and 2.5 g L^{-1} of water, respectively. In addition, pots were rotated every 3 to 5 days to minimize possible location effect on plant development.

2.4. Data collection and analysis

Data on plant phenology (days to flowering, plant height and days to maturity), number of pods per plant, number of grains per pod, weight of 100 grains, and grain yield per pot were recorded. These data were subjected to analysis of variance (ANOVA) using GenStat 14th Edition (VSN International, 2011). Mean differences among water stress treatments were determined according to the Tukey's Honest Significant Difference Method. The rate of yield decrease due to water stress treatments was estimated using the formula:

$$Y_d = [(Y_c - Y_t)/Y_c] \times 100$$

where: Y_d is the percentage of grain yield decrease; Y_c is the average yield obtained under the control "c"; and Y_t is the average yield obtained under the treatment "*t*".

3. Results

The present study disclosed that drought and waterlogging stresses had negative effect on plant growth and grain yield components of bush and climbing beans (Tables 5 and 6).

3.1. Number of days to flowering and days to physiological maturity

For both bush and climbing bean genotypes, water stress levels had a highly significant effect on the number of days from sowing to flowering ($p < 0.001$) and physiological maturity ($p < 0.001$). The drought stress at late stages of plant growth (pod setting and seed filling) accelerated the physiological maturity by 4 days on average. Whereas, waterlogging stress at early plant growth stages (emergence, vegetative) prolonged days to physiological maturity by 4 days on average for bush and climbing beans (Tables 5 and 6).

3.2. Plant height

Water stress treatments had a significant effect on plant height for bush bean ($p = 0.024$) and not so significant for climbing bean (0.679). Drought stress and waterlogging stress at the evaluated developmental stages reduced plant height for both bush and climbing bean genotypes (Tables 5 and 6). Higher reductions of pant height were observed under drought and waterlogging stress at vegetative and flowering stages. However, the shortest plants were observed for waterlogging stress at vegetative stage for bush bean (43 cm) and at flowering for climbing bean (144 cm).

3.3. Number of pods per plant and number of grains per pod

For both bush and climbing bean genotypes, water stress levels had a significant effect on the number of grains per pod. For climbing bean, no significant effect was observed in the number of pods per plant with water stress treatments, although a decrease was noticed for all treatment levels (Tables 5 and 6). For bush and climbing bean genotypes, the small numbers of grains per pod was observed under drought stress at pod setting and under waterlogging stress at flowering (Tables 5 and 6). The lowest number of grains per pod was obtained under waterlogging stress at flowering stage.

Table 5. Effect of drought and waterlogging stress on agronomic performance of bush bean (RWR2245)

Treatments†	Days to flowering	Days to P. maturity	Plant height (cm)	Pods/plant (number)	Grains/pod (number)	100-grains weight (g)	Yield (g/plant)
Control	38^{ab}	69^{bc}	53^{a}	23^{a}	4^{a}	50^{a}	21^{a}
DS-E	35^{b}	64^{d}	46^{ab}	20^{a}	3^{ab}	46^{abc}	18^{ab}
DS-V	39^{a}	65^{d}	44^{ab}	11^{bc}	3^{ab}	41^{abc}	18^{ab}
DS-F	38^{a}	66^{cd}	47^{ab}	10^{c}	3^{ab}	42^{abc}	17^{ab}
DS-P	38^{a}	64^{d}	49^{ab}	10^{c}	3^{ab}	42^{abc}	17^{ab}
DS-S	38^{a}	67^{d}	49^{ab}	11^{bc}	3^{ab}	41^{abc}	18^{ab}
WL-E	38^{a}	74^{a}	50^{ab}	16^{ab}	4^{a}	49^{ab}	16^{ab}
WL-V	39^{a}	72^{ab}	43^{b}	11^{bc}	3^{ab}	37^{c}	14^{b}
WL-F	39^{a}	68^{bcd}	48^{ab}	11^{bc}	3^{b}	41^{abc}	13^{b}
WL-P	38^{a}	69^{bc}	52^{ab}	11^{bc}	3^{ab}	42^{abc}	19^{ab}
WL-S	37^{ab}	70^{bc}	49^{ab}	12^{bc}	3^{ab}	39^{bc}	18^{ab}
p-value	<0.001	<0.001	0.024	<0.001	0.013	0.003	0.008
Significance‡	(***)	(***)	(*)	(***)	(*)	(**)	(**)
LSD (p = 5%)	1.766	3.579	7.790	4.332	0.752	9.225	5.307
CV (%)	3.3	3.7	11.5	25.1	16.7	15.3	21.8

Notes: Mean treatments estimated from eight plants per treatment (n = 8), Within the same column, values that differ according to analysis of variance ($p \leq 0.05$) and Tukey's Honest Significant Difference Method are marked with different small letters;.

‡(ns) = no significant; (*), (**), (***) = significant at 0.05, 0.01 and 0.001, respectively (F test).

†DS = Drought stress, WL = Waterlogging stress, E = Emergence, V = Vegetative, F = Flowering, P = Pod setting, S = Seed filling.

Table 6. Effect of drought and waterlogging stress on agronomic performance of climbing bean (MAC44)

Treatments†	Days to flowering	Days to P. maturity	Plant height (cm)	Pods/plant (number)	Grains/pod (number)	100-grains weight (g)	Yield (g/plant)
Control	43^{b}	83^{bc}	166	13	5^{ab}	63^{a}	24^{a}
DS-E	45^{ab}	78^{d}	150	10	5^{ab}	51^{ab}	23^{ab}
DS-V	44^{b}	79^{d}	149	9	4^{bc}	63^{a}	20^{abc}
DS-F	43^{b}	80^{cd}	147	11	4^{bc}	55^{ab}	21^{abc}
DS-P	42^{b}	80^{cd}	168	9	3^{c}	60^{a}	14^{bc}
DS-S	42^{b}	79^{d}	154	10	3^{c}	55^{ab}	18^{abc}
WL-E	48^{a}	87^{ab}	155	9	5^{a}	50^{ab}	19^{abc}
WL-V	43^{b}	88^{a}	148	9	4^{abc}	52^{ab}	16^{abc}
WL-F	44^{b}	86^{ab}	144	9	3^{c}	45^{b}	14^{c}
WL-P	43^{b}	86^{ab}	169	10	4^{bc}	58^{ab}	18^{abc}
WL-S	43^{b}	86^{ab}	165	8	4^{bc}	46^{b}	18^{abc}
p-value	<0.001	<0.001	0.579	0.603	<0.001	0.028	0.003
Significance‡	(***)	(***)	(ns)	(ns)	(***)	(*)	(**)
LSD (p = 5%)	2.944	3.569	40.02	5.949	1.208	16.53	7.389
CV (%)	4.8	3.1	18.2	42.9	21.3	21.6	27.8

Notes: Mean treatments estimated from n = 8 plants per treatment, Within the same column, values that differ according to analysis of variance ($p \leq 0.05$) and Tukey's Honest Significant Difference Method are marked with different small letters.

‡(ns) = no significant; (*), (**), (***) = significant at 0.05, 0.01 and 0.001, respectively (F test).

†DS = Drought stress, WL = Waterlogging stress, E = Emergence, V = Vegetative, F = Flowering, P = Pod setting, S = Seed filling.

3.4. Weight of 100 grains

Compared to the control (unstressed treatment), water stress conditions reduced weight of 100 grains in both cultivars significantly (Tables 5 and 6). The weight reduction was higher for waterlogging stress during vegetative for bush beans and seed filling for climbing bean. However, the lowest weight of 100 grains was observed for waterlogging stress at vegetative for bush bean and waterlogging stress at flowering and seed filling for climbing bean.

3.5. Grain yield

Highly significant differences were observed among water stress treatments for grain yield of both bush bean and climbing bean (Tables 5, 6 and Figure 1). For bush bean, the lowest grain yield was obtained under waterlogging stress at flowering stage and estimated at 13 and 14 g pot^{-1} for bush and climbing bean, respectively.

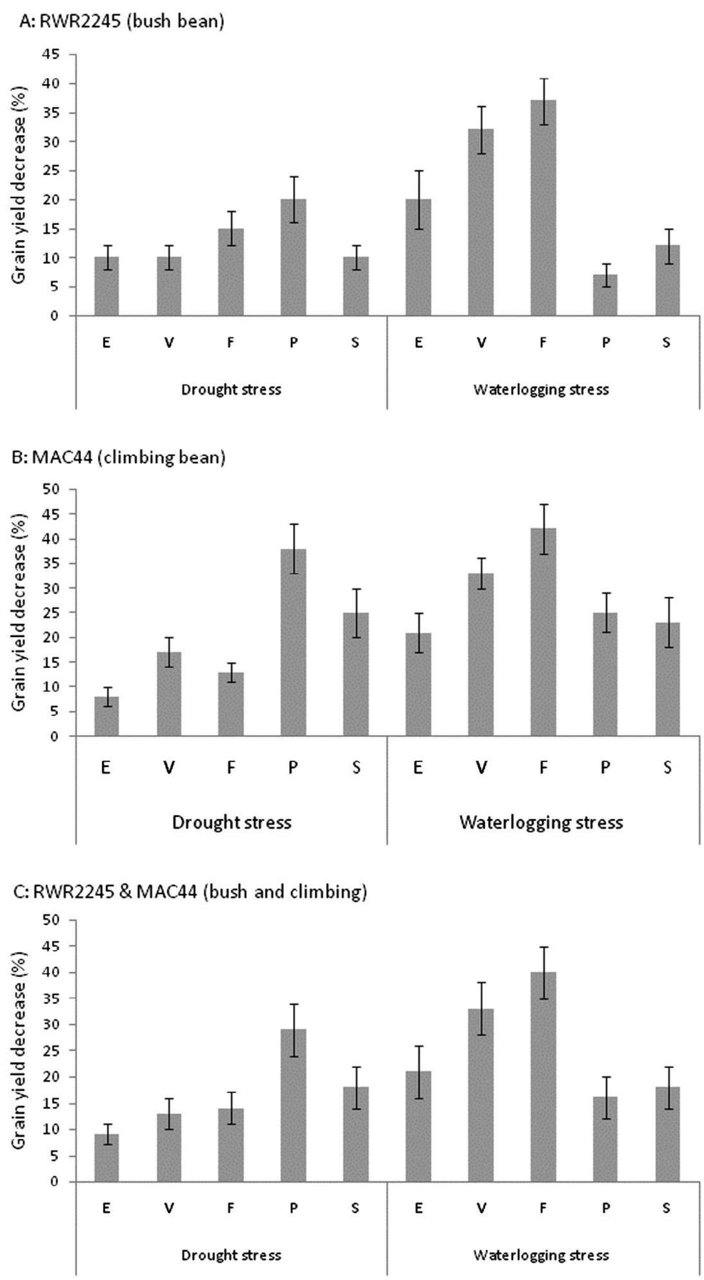


Figure 1. Effect of drought and waterlogging stress at different growth stages on grain yield decrease of bush bean (A), climbing bean (B) and common bean i.e. both types (C).

Notes: The *bars* mean value with standard error as determined from our experiment; E = Emergence, V = Vegetative, F = Flowering, P = Pod setting, S = Seed filling.

Water stress levels caused a reduction in grain yield in both cultivars as compared to the non-stressed treatment (Figure 1). Drought and waterlogging stress conditions appeared to have stronger effect on the grain yield of climbing bean than bush bean. Compared to the non-stressed treatment, waterlogging stress reduced grain yield by, on average, 22% and 29%, for bush and climbing bean, respectively. Whereas, drought stress reduced grain yield on average of 13%for bush bean and 20% for climbing bean. For both genotypes, pod setting and flowering stages were respectively most sensitive to drought and waterlogging, causing a yield reduction of 29% and 40% (Figure 1). In contrast, genotypes showed a better ability to recover from stress at emergence and vegetative stages than at reproductive stages.

4. Discussion

The effects of drought and waterlogging stress on agronomic attributes of bush and climbing bean genotypes varied. Some of the parameters were more sensitive to drought and waterlogging stress effects than others. Grain yield, days to flowering, days to physiological maturity, plant height, number of grains per pod, weight of 100 grains, grain yield were highly sensitive to water stresses, whereas plant height and number of pods per plant were the least sensitive for climbing bean type.

4.1. Days to physiological maturity

Significant reduction in days to physiological maturity as a result of water stress (drought stress) was observed in the present study which is consistent with previous reports (Beebe, Rao, Cajiao, & Grajales, 2008; Darkwa, Ambachew, Mohammed, Asfaw, & Blair, 2016; Muñoz-Perea, Allen, Westermann, Wright, & Singh, 2007). As reported by Acosta-Diaz, Acosta-Gallegos, Trejo-López, Padilla-Ramirez, and Amador-Ramirez (2009), most plant species have a tendency to escape from the effects of drought through a faster development in response to drought stress. Similar effects of drought stress on plant phenotype have previously been observed (Ramirez-Vallejo & Kelly, 1998). Therefore, the matching of crop phenotype to environmental conditions, mainly rainfall pattern, has been recognized as an important criterion for improving drought adaptation in common bean (Acosta-Diaz et al., 2009; Ramirez-Vallejo & Kelly, 1998).Waterlogging stress is also known to induce alterations in physiological mechanisms and cause adverse effects on several physiological and biochemical process of plants, due to the deficiency of essential nutrients like nitrogen, magnesium, potassium, and calcium (Ashraf, 2012). In addition, plants exposed to waterlogging stress exhibit stomatal closure, limited water uptake, oxygen deficiency and substantial decline of photosynthetic rate (Ashraf, 2012).

According to Ashraf (2012), reduction of photosynthetic capacity of plants under waterlogged conditions has been reported in different plant species by a number of researchers, for example, *Lolium perenne* (Mcfarlane, Ciavarella, & Smith, 1999), *Lycopersicon esculentum* (Bradford, 1983; Jackson,1990) *Pisum sativum* (Jackson & Kowalewska, 1983; Zhang & Davies, 1987) and *Triticum aestivum* (Trought & Drew, 1980).

4.2. Plant height

Drought and waterlogging stress reduced plant height for evaluated treatment combinations. The plant height decrease was of high magnitude for drought or waterlogging stress at vegetative and flowering stages. The decreased plant height induced by water stress in the young plants could be due to the reduction in plant water status which reduces shoot elongation and leaf expansion together with reduced photosynthesis activity that leads to the inhibition of the plant growth. Extreme moisture stress reduces the ability of plant to utilize soil nutrients and causes reduction in growth rate as well as changes in plant metabolic processes. This finding is in line with Ahmed et al. (2015) and Amri, El-Ouni, and Salem (2014) who reported that plant height, one of the indirect measures of the health of plants, is susceptible to environmental stresses occurred in early plant developmental phases. Similar results were found by Ranawake, Dahanayaka, Amarasingha, Rodrigo, and Rodrigo (2011) and Uddin, Parvin, and Awal (2013) who reported that plant height decreased for mungbean grown under no irrigation and it increased with the number of irrigations. This was attributed to the inhibition of cell division or cell enlargement under soil moisture stress. Limited vegetative growth of grain legume crops, when soil moisture reaches the lower (or above) values of required available water, was confirmed by Board et al. (1990), Lopez et al. (1996), Muchow (1985), Pilbeam et al. (1992), Remseur et al. (1984) and Xia, (1994) (as cited in Barrios, Hoogenboom, & Nesmith, 2005).

4.3. Yield components

Yield components are generally good indicators of evaluating crop performance under defined growing conditions. The present study showed significant reductions in number of grains per pod, 100 grain weight, and grain yield under drought and waterlogged conditions. Similarly, Asfaw and Blair (2014) reported significant reductions in pod number per plant, seed number per pod, 100 seed weight and seed yield of common beans under similar drought-stressed conditions. The results from our study indicate that vegetative and flowering growth stages are relatively more sensitive to waterlogging stress whilst pod setting and seed filling stages are more sensitive to drought stress. These results are consistent with the findings of Ambachew, Mekbib, Asfaw, Beebe, and Blair (2015) and Darkwa et al. (2016). They observed that, the late flowering and pod setting stages appear to be the most sensitive stages to soil moisture stress. Likewise, Liu, Christian, Jensen and Andersen (2008)reported that early seed development is extremely vulnerable to drought stress, mainly because it involves several processes that are highly sensitive to changes in plant water status. According to Emam, Shekoofa, Salehi, and Jalali (2010) and Miorini and Saad (2012), the reduction of grain yield in water stress as compared to the non-stress condition, may have been attributed to a lower percentage of pods formed due to flower abscission and embryo abortion when drought occurred at flowering and pod filling growth stages. While investigating drought stress and the distribution of vegetative and reproductive traits of a common bean cultivar, Barrios et al. (2005) indicated that total number of flowers in some varieties may be reduced up to 47% under drought conditions affecting the number of pods per plant. In addition, Hossain, Rahman, Rahman, Anwar, and Hossen (2010) and Uddin et al. (2013), in their studies on Mungbean (*Vigna radiata* L.) indicated that the percentage of flower and pod abscission increased with increase in soil moisture stress.

Waterlogging is more common and often causes considerable yield loss across plant species. According to Richee (2004) waterlogging stress can reduce soybean yield up to 43% during the vegetative growth stages and 56% during the reproductive stage. Waterlogging during vegetative (V2) and early reproductive (R1 to R3) stages is more damaging to grain yield than other stages (Toai et al., 2010). These yield losses are attributed to the reduced growth rate, reduced nutrient uptake, decrease of photosynthetic activity and incidence of diseases. There are a number of diseases that can take advantage of the wet conditions including *Phythophthora, Rhizoctinia, and Pythium*, among others (Scott, DeAngulo, Daniels, & Wood, 1989).

This study has positive implications for bean production in terms of both irrigation management and mitigation of the impacts of environmental stresses. Nowadays, deficit (or regulated deficit) irrigation is one way of maximizing water use efficiency for higher yields per unit of irrigation water applied (Bekele & Tilahun, 2007; Sadeghipour, 2008). Based on the results from the present study, deficit irrigation strategy may focus on withholding water supply at early plant growth stages (emergence, vegetative) of common bean. As confirmed by Sadeghipour (2008), water stress during certain growth stages may have more effect on grain yield than similar stress at other growth stages. From our study, grain yield reductions were higher for drought stress at pod setting stage and for waterlogging stress at vegetative and flowering stages. Therefore, insurance programmes may diversify their interventions by tailoring insurance products on these critical growth stages of common bean, while insuring floods and drought-stressed conditions.

5. Conclusions

Drought and waterlogging stresses are among rapidly increasing constraints to agricultural production particularly for short season grain legume crops such as common bean. Drought and waterlogging treatments reduced common bean yield regardless of whether the stress was applied in the vegetative or in the reproductive stage of plant development. However, drought stress at pod formation stage and waterlogging stress at vegetative and flowering stages, affected grain yield more severely than their occurrence at other growth stages. Based on the results from this study, for common bean, early plant growth stages (vegetative and flowering) are relatively more sensitive to waterlogging stress conditions whereas pod formation stage is most sensitive to drought-stressed conditions. To maximize bean production in dry areas, over-irrigation should be avoided at vegetative-flowering stages and normal irrigation extended across all phenological stages, especially during flowering and pod setting for bush bean and pod setting and seed filling for climbing bean.

Acknowledgements
This research was conducted under the "Bean Seed System Project" jointly implemented by the International Center for Tropical Agriculture (CIAT), Rwanda Agriculture Board (RAB), Institut des Sciences Agronomiques du Burundi (ISABU), Kenya Agriculture and Livestock Research Organization (KARLO), University of Nairobi (UoN). The inputs from Uzabakiriho Emmanuel, Setegn Gebeyehu and Idupulapati M. Rao are greatly acknowledged.

Funding
This work was financially supported by the Syngenta Foundation for Sustainable Agriculture (SFSA).

Competing Interest
The authors declare no competing interest.

Author details
Nepomuscene Ntukamazina[1]
E-mail: ndabanepo@gmail.com
Richard N. Onwonga[1]
E-mail: onwongarichard@gmail.com
Rolf Sommer[2]
E-mail: r.sommer@cgiar.org
Clare M. Mukankusi[2]
E-mail: c.mukankusi@cgiar.org
John Mburu[3]
E-mail: jmburu@yahoo.com
ORCID ID: http://orcid.org/0000-0001-6762-9979
Jean Claude Rubyogo[2]
E-mail: j.c.rubyogo@cgiar.org
[1] Department of Land Resource Management and Agricultural Technology, University of Nairobi, Nairobi, Kenya.
[2] International Center for Tropical Agriculture, Nairobi, Kenya.
[3] Department of Agricultural and Applied Economics, University of Nairobi, Nairobi, Kenya.

Citation information
Cite this article as: Effect of excessive and minimal soil moisture stress on agronomic performance of bush and climbing bean (*Phaseolus vulgaris* L.), Nepomuscene Ntukamazina, Richard N. Onwonga, Rolf Sommer, Clare M. Mukankusi, John Mburu & Jean Claude Rubyogo, *Cogent Food & Agriculture* (2017), 3: 1373414.

Corrigendum
This article was originally published with errors. This version has been corrected. Please see Corrigendum (https://doi.org/10.1080/23311932.2017.1386769).

Cover image
Source: Authors

References

Acosta-Diaz, E., Acosta-Gallegos, J. A., Trejo-López, C., Padilla-Ramirez, J. S., & Amador-Ramirez, M. D. (2009). Adaptation traits in dry bean cultivars grown under drought stress. *Agricultura Técnicaen México, 35*, 416–425.

Ahmed, A., Selim, M. M., Alderfasi, A. A., & Afzal, M. (2015). Effect of drought stress on mungbean (Vignaradiata L.) under arid climatic conditions of Saudi Arabia. *WIT Transactions on Ecology and the Environment, 192*, 1743–3541. doi:10.2495/ECO150171

Ahmed, F., Rafil, M. Y., Ismail, M. R., Juraimi, A. S., Rahim, H. A., Asfaliza, R., & Latif, M. A. (2013). Waterlogging tolerance of crops: Breeding, mechanism of tolerance, molecular approaches, and future prospects. *BioMed Research International,* 1–10.

Ambachew, D., Mekbib, F., Asfaw, A., Beebe, S. E., & Blair, M. W. (2015). Trait associations in common bean genotypes grown under drought stress and field infestation by BSM bean fly. *The Crop Journal, 3*, 305–316. https://doi.org/10.1016/j.cj.2015.01.006

Amri, M., El-Ouni, M. H., & Salem, M. B. (2014). Waterlogging affect the development, yield and components, chlorophyll content and chlorophyll fluorescence of six bread wheat genotypes (*Triticum aestivum* L.). *Bulgarian Journal of Agricultural Science, 20*, 647–657.

Apal Agricultural Laboratory. (2016). *Soil Test Interpretation Guide*. Retrieved November 25, 2016, from https://www.apal.com.au/Service-guide

Asfaw, A., & Blair, M. W. (2014). Quantification of drought tolerance in Ethiopian common bean varieties. *Agricultural Sciences, 5*, 124–139. https://doi.org/10.4236/as.2014.52016

Ashraf, M. A. (2012). Waterlogging stress in plants: A review. *African Journal of Agricultural Research, 7*, 1976–1981.

Barrios, A. N., Hoogenboom, G., & Nesmith, D. S. (2005). Drought stress and the distribution of vegetative and reproductive traits of a bean cultivar. *Scientia Agricola, 62*, 18–22. https://doi.org/10.1590/S0103-90162005000100004

Beebe, E. S., Rao, M. I., Blair, W. M., & Acosta-Gallegos, A. J. (2013). Phenotyping common beans for adaptation to drought. *Frontiers in Physiology, 4*, 1–20.

Beebe, S. E., Rao, I. M., Cajiao, C., & Grajales, C. M. (2008). Selection for drought resistance in common bean also improves yield in phosphorus limited and favorable environments. *Crop Science, 48*, 582–592. https://doi.org/10.2135/cropsci2007.07.0404

Beebe, S., Ramirez, J., Jarvis, A., Rao, I. M., Mosquera, G., Bueno, J. M., & Blair, M. W. (2011). *Genetic improvement of common beans and the challenges of climate change* (pp. 356–369). Richmond: Blackwell..

Bekele, S., & Tilahun, K. (2007). Regulated deficit irrigation scheduling of onion in a semi-arid region of Ethiopia. *Agricultural Water Management, 89*, 148–152. https://doi.org/10.1016/j.agwat.2007.01.002

Borella, J., Do Amarante, L., De Oliveira, D. S., De Oliveira, A. C. B., & Braga, E. J. B. (2014). Waterlogging-induced changes in fermentative metabolism in roots and nodules of soybean genotypes. *Science in Agriculture, 71*, 499–508.

Bradford, K. J. (1983). Effects of soil flooding on leaf gas exchange of tomato plants. *Plant Physiology, 73*, 475–479. https://doi.org/10.1104/pp.73.2.475

Buruchara, R., Mukankusi, C. M., Ampofo, K., & Walker, J. (2010). Bean disease and pest identification and management. *Handbooks for small-scale Seed producers* (45 pp.). International Center for Tropical Agriculture. ISSN 2220-3370.

Buruchara, R., Chirwa, R., Sperling, L., Mukankusi, C., Rubyogo, J. C., Mutonhi, R., & Abang, M. M. (2011). Development and delivery of bean varieties in Africa: The Pan-Africa Bean Research Alliance (PABRA) model. *African Crop Science Journal, 19*, 227–245.

Calvache, M., Reichardt, K., Bacchp, O. S., & Dourado-Neto, D. (1997). Deficit irrigation at different growth stages of the common bean (*Phaseolus vulgaris* L.). *Scientia Agricola Piracicaba, 54*, 1–16.

Chalwe, S., Mwiinga, M. & Tembo, G. (2011). *Factors influencing bean producers' choice of marketing channels in Zambia* (60 pp.) (Thesis). University of Zambia, Lusaka.

Cuellar-Ortiz, S. M., Arrieta-Montiel, M., Acosta-Gallegos, J., & Covartubias, A. A. (2008). Relationship between carbohydrate partitioning and drought resistance in common bean. *Plant, Cell and Environment, 31*, 1399–1409. https://doi.org/10.1111/pce.2008.31.issue-10

Cyamweshi, R. A., Tenywa, J. S., Makooma, M. T., Okiro, J. J., Dusengemungu, L., Mutimura, M., & Musoni, A. (2013). Farmers' coping mechanisms for common bean production under water-logged soil conditions in Uganda-Rwanda boarder region. *Journal of Environmental Science and Engineering B, 2*, 46–52.

Dagnew, K., Haileselassie, T., & Feyissa, T. (2014). Genetic diversity study of common bean (*Phaseolus vulgaris* L.) germoplasm from Ethiopia using inter simple sequence repeat (ISSR) markers. *African Journal of Biotechnology, 13*, 3638–3649.

Darkwa, K., Ambachew, D., Mohammed, H., Asfaw, A., & Blair, M. W. (2016). Evaluation of common bean (*Phaseolus vulgaris L.*) genotypes for drought stress adaptation in Ethiopia. *The Crop Journal, 4*, 367–376. https://doi.org/10.1016/j.cj.2016.06.007

Emam, Y., Shekoofa, A., Salehi, F., & Jalali, A. H. (2010). Water stress effects on two common bean cultivars with contrasting growth habits. *American-Eurasian Journal of Agricultural & Environmental Sciences, 9*, 495–499.

Food and Aagriculture Organisation. (2011). *Statistical database of the Food and Agriculture Organisation of the United Nations*. Rome: Author. Retrieved from https://faoatat.fao.org

Horneck, D. A., Sullivan, D. M., Owen, J. S., & Hart, J. M. (2011). *Soil test interpretation guide*. Corvallis, OR: Oregon State University, Extension service.

Hossain, M. B., Rahman, M. W., Rahman, M. N., Anwar, A. H. M. N., & Hossen, A. K. M. (2010). Effects of water stress on yield attributes and yield of different Mungbean genotypes. *International Journal of Sustainable Crop Production, 5*, 19–24.

Houk, E., Frasier, M. & Schuck, E. (2004, June 30–July 2). *The regional effects of waterlogging and soil salinization on a rural county in the Arkansas River Basin of Colorado*. Selected paper presented for presentation at the Western Agricultural Economics Association Annual Meeting, Honolulu, HI.

Jackson, M. B. (1990). Hormones and developmental change in plants subjected to submergence or soil waterlogging. *Aquatic Botany, 38*, 49–72. https://doi.org/10.1016/0304-3770(90)90098-6

Jackson, M. B., & Kowalewska, A. K. B. (1983). Positive and negative messages from root induce foliar desiccation and stomatal closure in flooded pea plants. *Journal of Experimental Botany, 34*, 493–506. https://doi.org/10.1093/jxb/34.5.493

Kalima, S. P. (2013). *Physiological responses of common bean (Phaseolus vulgaris L.) genotypes to water stress* (91 pp.) (MSc Thesis). University of Zambia, Lusaka.

Katungi, E., Farrow, A., Chianu, J., Sperling, L., & Beebe, S. (2009). *Common bean in Eastern and Southern Africa: A situation and outlook analysis*. Cali: CIAT.

Liu, F., Christian, R.Jensen, C.R., & Andersen, M.N. (2008). Effects of drought and salt stress during early reproductive growth stages in faba bean and quinoa. *IOP Conference Series: Earth and Environmental Science, 6*, doi:10.1088/1755-1307/6/7/372008.

Li, Y. P., You, M. P., Colmer, T. D., & Barbetti, M. J. (2015). Effect of timing and duration of soil saturation on soilborne *Pythium* diseases of common bean (*Phaseolus vulgaris*). *Plant Disease, 99*, 112–118. https://doi.org/10.1094/PDIS-09-13-0964-RE

Mcfarlane, N. M., Ciavarella, T. A., & Smith, K. (1999). The effect of waterlogging on growth, photosynthesis and biomass allocation in perennial ryegrass (*Lolium perenne* L.) genotypes with contrasting root development. *The Journal of Agricultural Science, 141*, 241–248. https://doi.org/10.1017/S0021859603003502

Meronuck, R., Wright, J. & Rehm, G. (2016). *IPM control of white mold in irrigated dry beans/Soil water monitoring methods*. University of Minnesota Extension. Retrieved October 9, 2016, from www.extension.umn.edu

Miorini, T. J., & Saad, C. J. (2012). *Productivity and water suppression in different beans (Phaseolus vulgaris* L.) *phenological stages* (5 pp.). College of Agronomical Science, Sao Paulo State University, Botucatu.

Mukankusi, C. M., Melis, R., Derera, J., Laing, M., & Buruchara, R. (2008). *Improving resistance to Fusarium root rot [Fusarium solani (Mart.) Sacc.f.spphaseoli (Burkholder) W.C. Snyder & H.N. Hans.] in common bean (Phaseolus vulgaris* L.) (201 pp.) (PhD Thesis). University of KwaZulu-Natal, Durban.

Muñoz-Perea, C. G., Allen, R. G., Westermann, D. T., Wright, J. L., & Singh, S. P. (2007). Water use efficiency among dry bean landraces and cultivars in drought-stressed and non-stressed environments. *Euphytica, 155*, 393–402. https://doi.org/10.1007/s10681-006-9340-z

Munyasa, A. J., Chemining'wa, G. N., Kimani, P. M., Mburu, M. W., & Nderitu, J. H. (2013). *Evaluation of drought tolerance mechanisms in Mesoamerican dry bean genotypes* (MSc Thesis). University of Nairobi, Nairobi.

Musoni, A., Butare, L., Mukankubana, D., Murwanashyaka, E., Kabeja, A., Rumongi, A., … Gahakwa, D. (2012). *Bean varieties information guide/released iron dense, high yielding, disease tolerant and marketable climbing and bush bean varieties* (34 pp.). Rwanda Agriculture Board.

Ostyula, R. M. (2010). *Nature of genetic control and inheritance of resistance to pythium root rot in bean genotypes* (PhD Thesis). Makerere University, Kampala.

Polania, J. A., Poschenrieder, C., Beebe, S., & Rao, I. M. (2016). Effective use of water and increased dry matter partitioned to grain contribute to yield of common bean improved for drought resistance. *Frontiers in Plant Science, 7*, 1–10.

Ramirez-Vallejo, P., & Kelly, J. D. (1998). Traits related to drought resistance in common bean. *Euphytica, 99*, 127–136. https://doi.org/10.1023/A:1018353200015

Ranawake, A. L., Dahanayaka, N., Amarasingha, U. S., Rodrigo, W. J., & Rodrigo, U. D. (2011). Effect of water stress on growth and yield of mung bean (*Vignaradiata* L.). *Tropical Agricultural Research & Extension, 14*, 201–204.

Richee, C. J. (2004). *Identification of soybean cultivars toleranceto waterlogging through analyses of leaf nitrogen concentration* (42 pages pp.) (MSc Thesis). Louisiana State University and Agricultural and Mechanical College, Baton Rouge, LA.

Sadeghipour, O. (2008). Effect of withholding irrigation at different growth stages on yield and yield component of Mungbean (*Vigna radiate L.*) Varieties. *American-Eurasian Journal of Agricultural & Environmental Sciences, 4*, 590–594.

Samboko, P. C. (2011). *An assessment of factors influencing the profitability of bean production in Zambia* (39 pp.) (BSc Dissertation). University of Zambia, Lusaka.

Scott, H. D., DeAngulo, J., Daniels, M. B., & Wood, L. S. (1989). Flood duration effects on soybean growth and yield. *Agronomy Journal, 81*, 631–636. https://doi.org/10.2134/agronj1989.00021962008100040016x

Sheppard, J., & Hoyle, F. (2016). *Water availability/fact sheet*. Western Australia: Department of Agriculture and Food. Retrieved October 27, 2016, from www.soilquality.org.au

Toai, T. T., Hoa, T. T., Hue, N. T., Nguyen, H. T., Shannon, J. G., & Rahman, M. A. (2010). Flooding tolerance of soybean [*Glycine max* (L.) Merr.] Germplasm from Southeast Asia under field and screen-house environments. *The Open Agriculture Journal,* 4, 38–46.

Trought, M. C. T., & Drew, M. C. (1980). The development of waterlogging damage in wheat seedlings (*Triticum aestivum* L.) I. Shoot and root growth in relation to changes in concentration of dissolved gases and solutes in the soil solutions. *Plant and Soil, 54*, 77–94. https://doi.org/10.1007/BF02182001

Uddin, S., Parvin, S., & Awal, M. A. (2013). Morpho-physiological aspects of mungbean *(vignaradiata* L.) in response to water stress. *International Journal of Agricultural Science and Research, 3*, 137–148.

VSN International. (2011). *GenStat for windows* (14th ed.). Hemel Hempstead: Author. Retrieved from https://GenStat.co.uk

Zhang, J., & Davies, W. J. (1987). ABA in roots and leaves of flooded pea plants. *Journal of Experimental Botany, 38*, 649–659. https://doi.org/10.1093/jxb/38.4.649