REFERENCES

Abate, T. 2012. Four Seasons of Learning and Engaging Smallholder Farmers Progress of Phase International Crops Research Institute for the Semi-Arid Tropics. Nairobi, Kenya.

Acosta-Gallegos, J., and J.W. White. 1994. Phenological Plasticity as an Adaptation by Common Bean to Rainfed Environments. Crop Science 35:199-204.

Acosta Gallegos, J.A. 1988. Selection of common bean (*Phaseolus vulgaris* L.) genotypes with enhanced drought tolerance and biological nitrogen fixation, Ph.D.Thesis Michigan State University, East Lansing, Michigan.

ÅGren, A.I., and O. Franklin. 2003. Root :Shoot Ratios, Optimization and Nitrogen Productivity. Annals of Botany 92:795-800.

ÅGren, G.I., and T. Ingestad. 1987. Root: Shoot ratio as a balance between nitrogen productivity and photosynthesis. Plant, Cell & Environment 10:579-586.

Ainsworth, E.A., C.R. Yendrek, J.A. Skoneczka, and S.P. Long. 2011. Accelerating yield potential in soybean: potential targets for biotechnological improvement. Plant, Cell & Environment 35:38-52.

Alsina, M.M., D.R. Smart, T. Bauerle, F. de Herralde, C. Biel, C. Stockert, C. Negron, and R. Save. 2011. Seasonal changes of whole root system conductance by a drought-tolerant grape root system. Journal of Experimental Botany 62:99-109.

Amede, T., and S. Schubert. 2003. Mechanisms of drought resistance in grain legumes I: Osmotic adjustment. SINET: Ethiopian Journal of Science 26:37-46.

Anjum, S.A., L. Wang, M. Farooq, I. Khan, and L. Xue. 2011. Methyl Jasmonate-Induced Alteration in Lipid Peroxidation, Antioxidative Defence System and Yield in Soybean Under Drought. Journal of Agronomy and Crop Science 197:296-301.

Anyia, A.O., D.J.Archambault, J.J. Slaski, and J.M.Nyachiro. 2005. Carbon isotope discrimination as a selection criterion for improved water use efficiency and productivity of barley on the prairies. 18thNorth American Barley Researchers Workshop and 4thCanadian Barley Symposium. Red Deer, Alberta, Canada:118-123.

Ao, J., J. Fu, J.Tian, X.Yan, and H. Liao. 2010. Genetic variability for root morph-architecture traits and root growth dynamics as related to phosphorus efficiency in soybean. Functional Plant Biology 37:304-312.

Araus, J.L., C. Sánchez, and G.O. Edmeades. 2011. Phenotyping maize for adaptation to drought. Monneveux P. and Ribaut J.M. (eds), Drought phenotyping in crops: from theory to practice. Generation Challenge Programme,pp.259-282.

Araus, J.L., T. Amaro, Casades, J. s, A. Asbati, and M.M. Nachit. 1998. Relationships between ash content, carbon isotope discrimination and yield in durum wheat. Functional Plant Biology 25:835-842.

Arrese-Igor, C., E.M. González, D. Marino, R. Ladrera, E. Larrainzar, and E. Gil-Quintana. 2011. Physiological response of legumes nodules to drought. Plant Stress 5:24-31.

Bacon, M.A. 2004. Water use efficiency in plant biology Blackwell Publishing Oxford, UK.

Baker, N.R. 1996. Photosynthesis and the Environment Springer.

Banziger, M., G. Edmeades, D. Beck, and M. Bellon. 2000. Breeding for drought and nitrogen stress tolerance in maize: from theory to practice. Mexico DF CIMMYT.

Bao, F., J. Shen, S.R. Brady, G.K. Muday, T. Asami, and Z. Yang. 2004. Brassinosteroids Interact with Auxin to Promote Lateral Root Development in Arabidopsis. Plant Physiology 134:1624-1631.

Beebe, S.E., IM Rao , Blair MW, and JA Acosta-Gallegos. 2010. Phenotyping common beans for adaptation to drought. In: Drought phenotyping: Theory and practice. (Monneveux P and Ribaut JM, eds.) pp. 311–334. Generation Challenge Programme, Texcoco, Mexico

Beebe, S.E., I. Ochoa, P. Skroch, J. Nienhuis, and J. Tivang. 1995. Genetic Diversity among Common Bean Breeding Lines Developed for Central America. Crop Science 35:1178-1183.

Beebe, S.E., M. Rojas-Pierce, X. Yan, M.W. Blair, F. Pedraza, F. Muñoz, J. Tohme, and J.P. Lynch. 2006. Quantitative Trait Loci for Root Architecture Traits Correlated with Phosphorus Acquisition in Common Bean. Crop Science 46:413-423.

Bergersen, F.J., and G.L. Turner. 1983. An evaluation of ^{15}N methods for estimating nitrogen fixation in a subterranean clover-perennial ryegrass sward. Australian Journal of Agricultural Research 34:391-401.

Blum, A. 2005. Drought resistance, water-use efficiency, and yield potential——are they compatible, dissonant, or mutually exclusive? Australian Journal of Agricultural Research 56:1159-1168.

Blum, A. 2011. Drought resistance - is it really a complex trait? Functional Plant Biology 38:753-757.

Boyer, J.S. 1982. Plant Productivity and Environment. Science 218:443-448.

Boyer, J.S., S.C. Wong, and G.D. Farquhar. 1997. CO_2 and Water Vapor Exchange across Leaf Cuticle (Epidermis) at Various Water Potentials. Plant Physiology 114:185-191.

Brady, N.C., and R.R. Weil. 2008. The nature and properties of soils Prentice Hall.

Brouwer, R. 1962. Nutritive influences on the distribution of dry matter in the plant. Neth. J. Agric. Sci. 10:399-408.

Brugnoli, E., and G.D. Farquhar. 2000. Photosynthetic fractionation of carbon isotopes, p. 399-434. In: R.C. Leegood, T.D.Sharkey, and S. von Caemmerer (eds.) Photosynthesis: physiology and metabolism. Advances in photosynthesis, Vol. 9. Clair Academic Publ., The Netherlands.

Buckley, T.N., G.D. Farquhar, and K.A. Mott. 1997. Qualitative effects of patchy stomatal conductance distribution features on gas-exchange calculations. Plant, Cell & Environment 20:867-880.

Casimiro, I., A. Marchant, R.P. Bhalerao, T. Beeckman, S. Dhooge, R. Swarup, N. Graham, D. Inzé, G. Sandberg, P.J. Casero, and M. Bennett. 2001. Auxin Transport Promotes Arabidopsis Lateral Root Initiation. The Plant Cell Online 13:843-852.

Castellanos, J., J.J. Peña-Cabriales, and J.A. Acosta-Gallegos. 1996a. ^{15}N-determined dinitrogen fixation capacity of common bean (*Phaseolus vulgaris*) cultivars under water stress. The Journal of Agricultural Science 126:327–333.

Castellanos, J.Z., J.J. Peña-Cabriales, and J.A. Acosta-Gallegos. 1996b. ^{15}N-determined dinitrogen fixation capacity of common bean (*Phaseolus vulgaris*) cultivars under water stress. The Journal of Agricultural Science 126:327-333.

Cha-um, S., and C. Kirdmanee. 2008. Effect of osmotic stress on proline accumulation, photosynthetic abilities and growth of sugarcane plantlets (*Saccharum officinarum* L.). Pakistan Journal of Botany 40:2541-2552.

Chaves, M.M. 1991. Effects of Water Deficits on Carbon Assimilation. Journal of Experimental Botany 42:1-16.

Chaves, M.M., and M.M. Oliveira. 2004. Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. Journal of Experimental Botany 55:2365-2384.

Chaves, M.M., J.P. Maroco, and J.S. Pereira. 2003. Understanding plant responses to drought --; from genes to the whole plant. Functional Plant Biology 30:239-264.

Chaves, M.M., J.S. Pereira, J. Maroco, M.L. Rodrigues, C.P.P. Ricardo, M.L. Osorio, I. Carvalho, T. Faria, and C. Pinheiro. 2002. How Plants Cope with Water Stress in the Field? Photosynthesis and Growth. Annals of Botany 89:907-916.

Chen, P., C.H. Sneller, L.C. Purcell, T.R. Sinclair, C.A. King, and T. Ishibashi. 2007. Registration of Soybean Germplasm Lines R01-416F and R01-581F for Improved Yield and Nitrogen Fixation under Drought Stress. Journal of Plant Registration 1:166-167.

CIAT. 1996. Bean program annual report, CIAT, Cali, Colombia.

CIAT. 2007. Bean program annual report, CIAT, Cali, Colombia.

CIAT. 2010. http://www.ciat.cgiar.org/Paginas/index.aspx [Online].

Comstock, J., and J. Ehleringer. 1993. Stomata1 Response to Humidity in Common Bean (*Phaseolus vulgaris*):Implications for Maximum Transpiration Rate, Water-use Efficiency and Productivity. Australian Journal Plant Physiology 20:669-691.

Condon, A.G., G.D. Farquhar, and R.A. Richards. 1990. Genotypic Variation in Carbon Isotope Discrimination and Transpiration Efficiency in Wheat. Leaf Gas Exchange and Whole Plant Studies. Functional Plant Biology 17:9-22.

Condon, A.G., R.A. Richards, G.J. Rebetzke, and G.D. Farquhar. 2002. Improving Intrinsic Water-Use Efficiency and Crop Yield. Crop Science 42:122-131.

Connor, D.J., R.S. Loomis, and K.G. Cassman. 1992. Crop Ecology: Productivity and Management in Agricultural Systems Cambridge University Press.

Coque, M., A. Martin, J. Veyrieras, B. Hirel, and A. Gallais. 2008. Genetic variation for N-remobilization and postsilking N-uptake in a set of maize recombinant inbred lines. 3. QTL detection and coincidences. TAG Theoretical and Applied Genetics 117:729-747.

Cornic, G. 2000. Drought stress inhibits photosynthesis by decreasing stomatal aperture - not by affecting ATP synthesis. Trends in Plant Science 5:187-188.

Costa Franca, M.G., A.T. Pham Thi, C. Pimentel, R.O. Pereyra Rossiello, Y. Zuily-Fodil, and D. Laffray. 2000. Differences in growth and water relations among *Phaseolus vulgaris*

cultivars in response to induced drought stress. Environmental and Experimental Botany 43:227-237.

Craufurd, P.Q., R.B. Austin, E. Acevedo, and M.A. Hall. 1991. Carbon isotope discrimination and grain-yield in barley. Field Crops Research 27:301-313.

CSA. 2010. Central Statistics Authority of Ethiopia, Annual Report.

DaCosta, M., and B. Huang. 2006. Changes in Carbon Partitioning and Accumulation Patterns during Drought and Recovery for Colonial Bentgrass, Creeping Bentgrass, and Velvet Bentgrass. Journal of the American Society for Horticultural Science 131:484-490.

Dakora, F.D., and S.O. Keya. 1997. Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan Africa. Soil Biology and Biochemistry 29:809-817.

De Dorlodot, S., B. Forster, L. Pagès, A. Price, R. Tuberosa, and X. Draye. 2007. Root system architecture: opportunities and constraints for genetic improvement of crops. Trends in Plant Science 12:474-481.

De Smet, I., T. Tetsumura, B. De Rybel, N. Frei dit Frey, L. Laplaze, I. Casimiro, R. Swarup, M. Naudts, S. Vanneste, D. Audenaert, D. Inzé, M.J. Bennett, and T. Beeckman. 2007. Auxin-dependent regulation of lateral root positioning in the basal meristem of *Arabidopsis*. Development 134:681-690.

Deleens, E., J.B. Cliquet, and J.L. Prioul. 1994. Use of ^{13}C and ^{15}N Plant Label Near Natural Abundance for Monitoring Carbon and Nitrogen Partitioning. Functional Plant Biology 21:133-146.

Denison, R.F. 1998. Decreased oxygen permeability: a universal stress response in legume root nodules. Botanica acta 111:191-192.

Denison, R.F., and B.L. Harter. 1995. Nitrate Effects on Nodule Oxygen Permeability and Leghemoglobin (Nodule Oximetry and Computer Modeling). Plant Physiology 107:1355-1364.

Ding, L., K.J. Wang, G.M. Jiang, D.K. Biswas, H. Xu, L.F. Li, and Y.H. Li. 2005. Effects of Nitrogen Deficiency on Photosynthetic Traits of Maize Hybrids Released in Different Years. Annals of Botany 96:925-930.

Dingkuhn, M., D.S.K. De, K. Dorffling, C. Javellana, and S. Datta. 1989. Varietal differences in leaf water potential, leaf net CO_2 assimilation, conductivity and water use efficiency in upland rice. Australian Journal of Agricultural Research 40:1183-1192.

Djekoun, A., and C. Planchon. 1990. Water Status Effect on Dinitrogen Fixation and Photosynthesis in Soybean. Agronomy Journal 83:316-322.

Ehleringer, J.R. 1988. Correlations between carbon isotope ratio, water use efficiency and yield. p165-191. *In*: J.W. White et al.(ed.) Research in drought tolerant in common bean. CIAT,Cali,Colombia.

Ehleringer, J.R. 1990. Correlations between Carbon Isotope Discrimination and Leaf Conductance to Water Vapor in Common Beans. Plant Physiology 93:1422-1425.

Elazab, A., G. Molero, M.D. Serret, and J.L. Araus. 2012. Root traits and $d^{13}C$ and $d^{18}O$ of durum wheat under different water regimes. Functional Plant Biology 39:379-393.

Esau, K. 1965. Plant anatomy. second ed. Wiley, Michigan, USA.

Evans, J.R. 1983. Nitrogen and Photosynthesis in the Flag Leaf of Wheat (*Triticum aestivum* L.). Plant Physiology 72:297-302.

Evans, J.R., T.D. Sharkey, J.A. Berry, and G.D. Farquhar. 1986. Carbon Isotope Discrimination measured Concurrently with Gas Exchange to Investigate CO_2 Diffusion in Leaves of Higher Plants. Functional Plant Biology 13:281-292.

FAO. 2001. Perfiles nutricionales por paises.Nicaragua. ftp:fao.org/es/esn/nutrition/ncp/nic/pdf. *In*:Beebe, S.E., IM Rao , Blair MW, and JA Acosta-Gallegos. 2010. Phenotyping common beans for adaptation to drought. In: Drought phenotyping: Theory and practice. (Monneveux P and Ribaut JM, eds.) pp. 311–334. Generation Challenge Programme, Texcoco, Mexico

FAO. 2003. http//apps.fao.org/page/collections.

FAO. 2006. FAOSTAT: FAO Stastical Databases. http://faostat.fao.org/.

FAO. 2008. *In*:Alene, A., O. Coulibaly, H. Tefera, S. Boahen, and D. Chikoye. 2011. Targeting Cowpea & Soybean Breeding & Seed Delivery: IITA, 3rd ESA Annual Review & Planning Meeting ;22-26 August 2011, Lilongwe, Malawi.

FAOSTAT. 2010. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor [Online].

Farquhar, G.D., and R.A. Richards. 1984. Isotopic Composition of Plant Carbon Correlates With Water-Use Efficiency of Wheat Genotypes. Functional Plant Biology 11:539-552.

Farquhar, G.D., M.H. O'Leary, and J.A. Berry. 1982. On the Relationship Between Carbon Isotope Discrimination and the Intercellular Carbon Dioxide Concentration in Leaves. Functional Plant Biology 9:121-137.

Farquhar, G.D., J.R. Ehleringer, and K.T. Hubick. 1989. Carbon Isotope Discrimination and Photosynthesis. Annual Review of Plant Physiology and Plant Molecular Biology 40:503-537.

Fenta, B.A., S.P. Driscoll, K.J. Kunert, and C.H. Foyer. 2011. Characterization of Drought-Tolerance Traits in Nodulated Soya Beans: The Importance of Maintaining Photosynthesis and Shoot Biomass Under Drought-Induced Limitations on Nitrogen Metabolism. Journal of Agronomy and Crop Science 198:92-103.

Fernandez-Luquen˜F., Dendooven L., Munive A. , Corlay-Chee L. , Serrano-Covarrubias L.M. , and Espinosa-Victoria D. 2008. Micro-morphology of common bean (*Phaseolus vulgaris* L.) nodules undergoing senescence. Acta Physiologiae Plantarum 30:545–552.

Fitter, A.H. 1987. An Architectural Approach to the Comparative Ecology of Plant Root Systems. New Phytologist 106:61-77.

Flexas, J., and H. Medrano. 2002. Drought-inhibition of Photosynthesis in C_3 Plants: Stomatal and None-stomatal Limitations Revisited. Annals of Botany 89:183-189.

Flexas, J., J. Bota, F. Loreto, G. Cornic, and T.D. Sharkey. 2004. Diffusive and Metabolic Limitations to Photosynthesis under Drought and Salinity in C_3 Plants. Plant Biology 6:269-279.

Flexas, J., J. Bota, J. Galmés, H. Medrano, and M. Ribas-Carbó. 2006a. Keeping a positive carbon balance under adverse conditions: responses of photosynthesis and respiration to water stress. Physiologia Plantarum 127:343-352.

Flexas, J., M. Ribas-Carbó, J. Bota, J. Galmés, M. Henkle, S. Martínez-Cañellas, and H. Medrano. 2006b. Decreased Rubisco activity during water stress is not induced by decreased relative water content but related to conditions of low stomatal conductance and chloroplast CO_2 concentration. New Phytologist 172:73-82.

Foster, E.F., A. Pajarito, and J. Acosta-Gallegos. 1995. Moisture stress impact on N partitioning, N remobilization and N-use efficiency in beans (*Phaseolus vulgaris*). The Journal of Agricultural Science 124:27-37.

Foyer, C.H., A.J. Bloom, G. Queval, and G. Noctor. 2009. Photorespiratory Metabolism: Genes, Mutants, Energetics, and Redox Signaling. Annual Review of Plant Biology 60:455-484.

Garay, A.F., and W.W. Wilhelm. 1982. Root System Characteristics of Two Soybean Isolines Undergoing Water Stress Conditions. Agronnomy Journal 75:973-977.

Garnett, T., V. Conn, and B.N. Kaiser. 2009. Root based approaches to improving nitrogen use efficiency in plants. Plant, Cell & Environment 32:1272-1283.

Garside, A.L., R.J. Lawn, and D.E. Byth. 1992. Irrigation management of soybean (*Glycine max* (L.) Merrill) in a semi-arid tropical environment. I. Effect of irrigation frequency on growth, development and yield. Australian Journal of Agricultural Research 43:1003-1017.

Gebeyehu, S. 2006. Physiological Response to Drought Stress of Common Bean (*Phaseolus vulgaris* L.) Genotypes Differing in Drought Resistance, Justus-Liebig-Universität Giessen, Germany.

George T., P. W. Singleton, and C.v. Kessel. 1996. The use of nitrogen ^{15} natural abundance and nitrogen yield of non nodulating isolines to estimate nitrogen fixation by soybeans (*Glycine max* L.) across three elevations. Biology and Fertility of Soils 15:81-86.

Ghannoum, O. 2009. C $_4$ Photosynthesis and water stress. Annals of Botany 103:635-644.

Gilbert, M.E., M.A. Zwieniecki, and N.M. Holbrook. 2011. Independent variation in photosynthetic capacity and stomatal conductance leads to differences in intrinsic water use efficiency in 11 soybean genotypes before and during mild drought. Journal of Experimental Botany 62:2875-2887.

Gimenez, C., V.J. Mitchell, and D.W. Lawlor. 1992. Regulation of Photosynthetic Rate of Two Sunflower Hybrids under Water Stress. Plant Physiology 98:516-524.

Gordon, A.J., F.R. Minchin, C.L. James, and O. Komina. 1999. Sucrose Synthase in Legume Nodules Is Essential for Nitrogen Fixation. Plant Physiology 120:867-878.

Graham, P.H., and C.P. Vance. 2003. Legumes: Importance and Constraints to Greater Use. Plant Physiology 131:872-877.

Gresshoff, P.M. 2010. Molecular Genetic Analysis of Nodulation Genes in Soybean, p. 275-318 Plant Breeding Reviews. John Wiley & Sons, Inc.

Grzesiak, S., W. Filek, S. Pienkowski, and B. Nizio. 1996. Screening for Drought Resistance: Evaluation of Drought Susceptibility Index of Legume Plants under Natural Growth Conditions. Journal of Agronomy and Crop Science 177:237-244.

Hall, A.E., R.A. Richards, A.G. Condon, G.C. Wright, and G.D. Farquhar. 1998. Carbon Isotope Discrimination and Plant Breeding, p. 81-113 Plant Breeding Reviews. John Wiley & Sons, Inc.

Hardarson, G., F.A. Bliss, M.R. Cigales-Rivero, R.A. Henson, J.A. Kipe-Nolt, L. Longeri, A. Manrique, J.J. Peña-Cabriales, P.A.A. Pereira, C.A. Sanabria, and S.M. Tsai. 1993. Genotypic variation in biological nitrogen fixation by common bean. Plant and Soil 152:59-70.

Hardarson G., F.A. Bliss, M.R. Cigales-Rivero, R.A. Henson, J.A. Kipe-Nolt, L. Longeri, A. Manrique, J.J. Pena-Cabriales, P.A.A. Preira, C.A.S. and, and S.M. Tsai. 1993. Genotypic variation in biological nitrogen fixation by common bean. Plant and Soil 152:59-70.

Hardy, R.W.F., R.C. Burns, and R.D. Holsten. 1973. Applications of the acetylene-ethylene assay for measurement of nitrogen fixation. Soil Biology and Biochemistry 5:47-81.

Harmon, C. 1957. Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide. Geochimica et Cosmochimica Acta 12:133-149.

Hay, R.K.M., and J.R. Porter. 2006. The physiology of crop yield. Scond ediition ed. Blackwell publishing Ltd.

Herridge, D.F., and S.K.A. Danso. 1995. Enhancing crop legume N_2 fixation through selection and breeding. Plant and Soil 174:51-82.

Herridge, D.F., M.B. Peoples, and R.M. Boddey. 2008. Global inputs of biological nitrogen fixation in agricultural systems Plant and Soil Volume 311, :1-18.

Hoagland, D.R., and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Circular. California Agricultural Experiment Station 347:32 pp.

HÖGberg, P. 1997. Tansley Review No. 95 15N natural abundance in soil-plant systems. New Phytologist 137:179-203.

Holdensen, L., H. Hauggaard-Nielsen, and E. Jensen. 2007. Short-range spatial variability of soil $\delta^{15}N$ natural abundance – effects on symbiotic N_2-fixation estimates in pea. Plant and Soil 298:265-272.

Hubick, K., and G. Farquhar. 1989. Carbon isotope discrimination and the ratio of carbon gained to water lost in barley cultivars. Plant, Cell & Environment 12:795-804.

Hubick, K.T., G.D. Farquhar, and R. Shorter. 1986. Correlation Between Water-Use Efficiency and Carbon Isotope Discrimination in Diverse Peanut (*Arachis*) Germplasm. Functional Plant Biology 13:803-816.

Hufstetler, E.V., H.R. Boerma, T.E. Carter, and H.J. Earl. 2007. Genotypic Variation for Three Physiological Traits Affecting Drought Tolerance in Soybean. Crop Science 47:25-35.

Hungria, M., and M.A.T. Vargas. 2000. Environmental factors affecting N_2 fixation in grain legumes in the tropics, with an emphasis on Brazil. Field Crops Research 65:151-164.

Hunt, S., B.J. King, and D.B. Layzell. 1989. Effects of Gradual Increases in O_2 Concentration on Nodule Activity in Soybean. Plant Physiology. 91:315-321.

IITA. 2000. Annual report 2000 (Project 4). Improving maize-grain legume systems in west and central Africa.

IITA. 2009a. http://www.iita.org/ [Online].

IITA. 2009b. http://r4dreview.org/ [Online].

JMP®8.02. 2011. Statistical Discovery Software; SAS Institute, Inc.: Cary, NC, USA.

Johnson, D.A., and K.H. Asay. 1993. Viewpoint: Selection for Improved Drought Response in Cool-Season Grasses. Journal of Range Management 46:194-202

Johnson, D.A., and M.D. Rumbaugh. 1995. Genetic Variation and Inheritance Characteristics for Carbon Isotope Discrimination in Alfalfa. Journal of Range Management 48:126-131.

Johnson, D.A., K.H. Asay, L.L. Tieszen, J.R. Ehleringer, and P.G. Jefferson. 1990. Carbon Isotope Dicrimination: Potential in Screening Cool-Season Grasses for Water-Limited Environments. Crop Science 30:338-343.

Johnson, R.C., and L.L. Tieszen. 1994. Variation for Water-Use Efficiency in Alfalfa Germplasm. Crop Science 34:452-458.

Jongdee, B., S. Fukai, and M. Cooper. 2002. Leaf water potential and osmotic adjustment as physiological traits to improve drought tolerance in rice. Field Crops Research 76:153-163.

Jury, W.A., H.J. Vaux Jr, and L.S. Donald. 2007. The Emerging Global Water Crisis: Managing Scarcity and Conflict Between Water Users, p. 1-76 Advances in Agronomy, Vol. Volume 95. Academic Press.

Kapotis, G., G. Zervoudakis, T. Veltsistas, and G. Salahas. 2003. Comparison of Chlorophyll Meter Readings with Leaf Chlorophyll Concentration in Amaranthus vlitus: Correlation with Physiological Processes1. Russian Journal of Plant Physiology 50:395-397.

Kashiwagi, J., L. Krishnamurthy, J.H. Crouch, and R. Serraj. 2006. Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L.) under terminal drought stress. Field Crops Research 95:171-181.

Khazaei, H., S.-D. Mohammady, M. Zaharieva, and P. Monneveux. 2009. Carbon isotope discrimination and water use efficiency in Iranian diploid, tetraploid and hexaploid wheats grown under well-watered conditions. Genetic Resources and Crop Evolution 56:105-114.

Kim, T.H., Böhmer Maik , H. Hu, N. Nishimura, and J.I. Schroeder. 2010. Guard Cell Signal Transduction Network: Advances in Understanding Abscisic Acid, $C0_2$, and Ca^{2+} Signaling. Annual Review of Plant Biology.

King, C.A., and L.C. Purcell. 2001. Soybean Nodule Size and Relationship to Nitrogen Fixation Response to Water Deficit. Crop Science 41:1099-1107.

King, C.A., and L.C. Purcell. 2005. Inhibition of N2 Fixation in Soybean Is Associated with Elevated Ureides and Amino Acids. Plant Physiology 137:1389-1396.

King, C.A., and L.C. Purcell. 2006. Genotypic Variation for Shoot N Concentration and Response to Water Deficits in Soybean. Crop Science 46:2396-2402.

Kirda, C., S. Danso, and F. Zapata. 1989. Temporal water stress effects on nodulation, nitrogen accumulation and growth of soybean. Plant and Soil 120:49-55.

Knight, J., F. Verhees, C. Van Kessel, and A. Slinkard. 1993. Does carbon isotope discrimination correlate with biological nitrogen fixation? Plant and Soil 153:151-153.

Kobata, T., T. Okuno, and T. Yamamoto. 1996. Contributions of capacity for soil water extraction and water use efficiency to maintenance of dry matter production in rice subjected to drought. Japan Journal of Crop Science 65 652–662.

Kohi, D.H., G. Shearer, and J.E. Harper. 1980. Estimates of N_2 Fixation Based on Differences in the Natural Abundance of ^{15}N in Nodulating and Nonnodulating Isolines of Soybeans. Plant Physiology 66:61-65.

Kondo, M., P. Pablico, D. Aragones, and R. Agbisit. 2004. Genotypic variations in carbon isotope discrimination, transpiration efficiency, and biomass production in rice as affected by soil water conditions and N. Plant and Soil 267:165-177.

Kumarasinghe, K.S., C. Kirda, A.R.A.G. Mohamed, F. Zapata, and S.K.A. Danso. 1992. ^{13}C isotope discrimination correlates with biological nitrogen fixation in soybean (*Glycine max* (L.) Merrill) Plant and Soil 139:145-147.

Ladrera, R., D. Marino, E. Larrainzar, E.M. González, and C. Arrese-Igor. 2007. Reduced Carbon Availability to Bacteroids and Elevated Ureides in Nodules, But Not in Shoots, Are Involved in the Nitrogen Fixation Response to Early Drought in Soybean. Plant Physiology 145:539-546.

Larcher, W. 2003. Physiological plant ecology: ecophysiology and stress physiology of functional groups. Fourth ed. Springer, Germany

Lawlor, D.W. 2002a. Limitation to Photosynthesis in Water-stressed Leaves: Stomata vs. Metabolism and the Role of ATP. Annals of Botany 89:871-885.

Lawlor, D.W. 2002b. Limitation to Photosynthesis in Water-stressed Leaves: Stomata. Annals of Botany 89:871-885.

Lawlor, D.W., and G. Cornic. 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant, Cell & Environment 25:275-294.

Lawlor, D.W., and W. Tezara. 2009a. Causes of decreased photosynthetic rate and metabolic capacity in water-deficient leaf cells: a critical evaluation of mechanisms and integration of processes. Annals of Botany.

Lawlor, D.W., and W. Tezara. 2009b. Causes of decreased photosynthetic rate and metabolic capacity in water-deficient leaf cells: a critical evaluation of mechanisms and integration of processes. Annals of Botany 103:561-579.

Lawn, R.J., and A.T. James. 2011. Application of physiological understanding in soybean improvement. I. Understanding phenological constraints to adaptation and yield potential. Crop and Pasture Science 62:1-11.

Leport, L., N.C. Turner, R.J. French, M.D. Barr, R. Duda, S.L. Davies, D. Tennant, and K.H.M. Siddique. 1999. Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. European Journal of Agronomy 11:279-291.

Li, X., Y. Feng, and L. Boersma. 1994. Partition of photosynthates between shoot and root in spring wheat (*Triticum aestivum* L.) as a function of soil water potential and root temperature. Plant and Soil 164:43-50.

Li, Z., P. Mu, C. Li, H. Zhang, Z. Li, Y. Gao, and X. Wang. 2005. QTL mapping of root traits in a doubled haploid population from a cross between upland and lowland *japonica* rice in three environments. TAG Theoretical and Applied Genetics 110:1244-1252.

Liang, Y., and J.M. Harris. 2005. Response of root branching to abscisic acid is correlated with nodule formation both in legumes and nonlegumes. American Journal of Botany 92:1675-1683.

Liang, Y., D.M. Mitchell, and J.M. Harris. 2007. Abscisic acid rescues the root meristem defects of the *Medicago truncatula* latd mutant. Developmental Biology 304:297-307.

Liu, F., M.N. Andersen, S.-E. Jacobsen, and C.R. Jensen. 2005. Stomatal control and water use efficiency of soybean (*Glycine max* L. Merr.) during progressive soil drying. Environmental and Experimental Botany 54:33-40.

Lopes, M.S., J.L. Araus, P.D.R. van Heerden, and C.H. Foyer. 2011. Enhancing drought tolerance in C_4 crops. Journal of Experimental Botany 62:3135-3153.

Lucas, M., C. Godin, C. Jay-Allemand, and L. Laplaze. 2008. Auxin fluxes in the root apex co-regulate gravitropism and lateral root initiation. Journal of Experimental Botany 59:55-66.

Lynch, J. 1995. Root Architecture and Plant Productivity. Plant Physiology 109:7-13.

Lynch, J., and K. Brown. 2001. Topsoil foraging - an architectural adaptation of plants to low phosphorus availability. Plant and Soil 237:225-237.

Lynch, J., M. Ho, and L. phosphorus. 2005. Rhizoeconomics: Carbon costs of phosphorus acquisition. Plant and Soil 269:45-56.

Lynch, J.P. 2007. TURNER REVIEW No. 14 Roots of the Second Green Revolution. Australian Journal of Botany 55:493-512.

Lynch, J.P. 2011. Root Phenes for Enhanced Soil Exploration and Phosphorus Acquisition: Tools for Future Crops. Plant Physiology 156:1041-1049.

Malamy, J.E. 2005. Intrinsic and environmental response pathways that regulate root system architecture. Plant, Cell & Environment 28:67-77.

Manavalan, L.P., S.K. Guttikonda, L.-S. Phan Tran, and H.T. Nguyen. 2009. Physiological and Molecular Approaches to Improve Drought Resistance in Soybean. Plant and Cell Physiology 50:1260-1276.

Mario Valenzuela-Vazquez , Artemio Escobedo-Mendoza, Jose Luis Almanza-Sandoval , and Asunción Ríos-Torres. 1997. Pressure bomb. Final report: New Mexico state University

Markwell, J., J. Osterman, and J. Mitchell. 1995. Calibration of the Minolta SPAD-502 leaf chlorophyll meter. Photosynthesis Research 46:467-472.

Martin, B., and Y.R. Thorstenson. 1988. Stable Carbon Isotope Composition ($d^{13}C$), Water Use Efficiency, and Biomass Productivity of *Lycopersicon esculentum*, *Lycopersicon pennellii*, and the F1 Hybrid. Plant Physiology 88:213-217.

Matamoros, M.A., L.M. Baird, P.R. Escuredo, D.A. Dalton, F.R. Minchin, I. Iturbe-Ormaetxe, M.C. Rubio, J.F. Moran, A.J. Gordon, and M. Becana. 1999. Stress-Induced Legume Root Nodule Senescence. Physiological, Biochemical, and Structural Alterations. Plant Physiology 121:97-112.

Mayers, J.D., R.J. Lawn, and D.E. Byth. 1991. Adaptation of soybean (*Glycine max* (L.) Merrill) to the dry season of the tropics. II. Effects of genotype and environment on biomass and seed yield. Australian Journal of Agricultural Research 42:517-530.

McCoy, E.L., L. Boersma, and M. Ekasingh. 1990. Net Carbon Allocation in Soybean Seedlings as Influenced by Soil Water Stress at Two Soil Temperatures. Botanical Gazette 151:497-505.

Medrano, H., J.M. Escalona, J. Bota, J. GulÃ□As, and J. Flexas. 2002. Regulation of Photosynthesis of C_3 Plants in Response to Progressive Drought: Stomatal Conductance as a Reference Parameter. Annals of Botany 89:895-905.

Mencuccini, M., S. Mambelli, and J. Comstock. 2000. Stomatal responsiveness to leaf water status in common bean (*Phaseolus vulgaris* L.) is a function of time of day. Plant, Cell & Environment 23:1109-1118.

Menéndez, C.M., and A.E. Hall. 1996. Heritability of Carbon Isotope Discrimination and Correlations with Harvest Index in Cowpea. Crop Science 36:233-238.

Merah, O., E. Deléens, and P. Monneveux. 2001. Relationships between carbon isotope discrimination, dry matter production, and harvest index in durum wheat. Journal of Plant Physiology 158:723-729.

Minchin, F.R. 1997. Regulation of oxygen diffusion in legume nodules. Soil Biology and Biochemistry 29:881-888.

Minolta. 1990. Specifications in detail—Chlorophyll meter SPAD 502. Minolta Technical Note TE102-601-01.

Miyashita, K., S. Tanakamaru, T. Maitani, and K. Kimura. 2005. Recovery responses of photosynthesis, transpiration, and stomatal conductance in kidney bean following drought stress. Environmental and Experimental Botany 53:205-214.

Mohamed, M., N. Keutgen, AA. Tawfik, and G. Noga. 2002. Dehydration-avoidance responses of tepary bean lines differing in drought resistance. Journal of Plant Physiology 159:31–38.

Morgan, J.A., D.R. LeCain, T.N. McCaig, and J.S. Quick. 1993. Gas Exchange, Carbon Isotope Discrimination, and Productivity in Winter Wheat. Crop Science 33:178-186.

Morgan, J.M. 1992. Adaptation to water deficits in three grain legume species. Mechanisms of turgor maintenance. Field Crops Research 29:91-106.

Morgan, J.M., and A.G. Condon. 1986. Water Use, Grain Yield, and Osmoregulation in Wheat. Functional Plant Biology 13:523-532.

Mostajeran, A., and Z. Rengel. 2007. Correlation Between the Carbon Isotope Composition ($d^{13}C$) of *Puccinellia ciliata* and *Balansa Clover* in Duel Stresses of Waterlogging and Salinity (NaCl). Scientia Iranica 327-335.

Müller, P., X.-P. Li, and K.K. Niyogi. 2001. Non-Photochemical Quenching. A Response to Excess Light Energy. Plant Physiology 125:1558-1566.

Munn, S. Bosch, and L. Alegre. 2004. Die and let live: leaf senescence contributes to plant survival under drought stress. Functional Plant Biology 31:203-216.

Muñoz-Perea, C., R. Allen, D. Westermann, J. Wright, and S. Singh. 2007. Water use efficiency among dry bean landraces and cultivars in drought-stressed and non-stressed environments. Euphytica 155:393-402.

Negash, K., S. Genbeyehu, K. Tumsa, and E. Habte. 2011. Enhancing. Progress and Prospects with research and development of TLII in Ethiopia, 3rd ESA Annual Review & Planning Meeting;22-26 August 2011, Lilongwe, Malawi.

Nguyen, H.T., R.C. Babu, and A. Blum. 1997. Breeding for Drought Resistance in Rice: Physiology and Molecular Genetics Considerations. Crop Science 37:1426-1434.

Nibau, C., D.J. Gibbs, and J.C. Coates. 2008. Branching out in new directions: the control of root architecture by lateral root formation. New Phytologist 179:595-614.

Nielsen, K.L., J.P. Lynch, and H.N. Weiss. 1997. Fractal Geometry of Bean Root Systems: Correlations between Spatial and Fractal Dimension. American Journal of Botany 84:26-33.

O'Leary, M.H. 1981. Carbon isotope fractionation in plants. Phytochemistry 20:553-567.

O'Leary, M.H. 1988. Carbon Isotopes in Photosynthesis. BioScience 38:328-336

O'Toole, J.C., and S.K. De Datta. 1986. Drought resisistance in rainfed lowland rice. Progress in rainfed rice. IRRI, Los Banos, Philippines, pp 145-158.

Ort, D., O. K, and W. RR. 1994. Depression of photosynthesis in crops with water deficits. In: Baker NR, Bowyer JR, eds. Photoinhibition of photosynthesis from molecular mechanism to the field., p. 315-329. Oxford: BIOS Science Publishers Ltd, .

Osmond, B., M. Badger, K. Maxwell, O. Bjorkman, and R. Leegood. 1997. Too many photos: photorespiration, photoinhibition and photooxidation. Trends Plant Science 2:119-121.

Osmont, K.S., R. Sibout, and C.S. Hardtke. 2007. Hidden Branches: Developments in Root System Architecture. Annual Review of Plant Biology 58:93-113.

Pantuwan, G., S. Fukai, M. Cooper, S. Rajatasereekul, and J.C. O'Toole. 2002. Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands: Part 1. Grain yield and yield components. Field Crops Research 73:153-168.

Parry, M.A.J., P.J. Andralojc, S. Khan, P.J. Lea, and A.J. Keys. 2002. Rubisco Activity: Effects of Drought Stress. Annals of Botany 89:833-839.

Pask, A., J. Pietragalla, DM. Mullan, and MP. Reynolds (Eds.). 2012. Physiological Breeding II: A Field Guide to Wheat Phenotyping. :CIMMYT, Mexico, D.F.

Passioura, J.B. 1996. Drought and drought tolerance. Plant Growth Regulation 20:79-83.

Pastenes, C., P. Pimentel, and J. Lillo. 2005. Leaf movements and photoinhibition in relation to water stress in field-grown beans. Journal of Experimental Botany 56:425-433.

Pate, J.S., C.A. Atkins, D.B. Layzell, and B.J. Shelp. 1984. Effects of N_2 Deficiency on Transport and Partitioning of C and N in a Nodulated Legume. Plant Physiology 76:59-64.

Pazdernik, D.L., P.H. Graham, and J.H. Orf. 1997. Heritability in the early nodulation of F_3 and F_4 soybean lines. Canadian Journal of Plant Science 77:201-205.

Pazdernik, D.L., P.H. Graham, C.P. Vance, and J.H. Orf. 1996. Host Genetic Variation in the Early Nodulation and Dinitrogen Fixation of Soybean. Crop Science 36:1102-1107.

Peña-Cabriales J., and J. Castellanos. 1993. Effect of water stress on N2 fixation and grain yield of Phaseolus vulgaris L. . Plant Soil 152.

Peoples, M.B., and D.F. Herridge. 1990. Nitrogen fixation by legumes in tropical and subtropical agriculture CSIRO Division of Plant Industry, Canberra, A.C.T., Australia.

Peoples, M.B., U. Murray John, and H. David. 2009. Measuring symbiotic nitrogen fixation by legumes. In: Nitrogen fixation in crop production / D. W. Emerich and H. B. Krishnan [eds], pp.125-170 American Society of Agronomy.

Peoples, M.B., A.W. Faizah, B. Rerkasem, and D.F. Herridge. 1989. Methods for evaluating nitrogen fixation by nodulated legumes in the field Australian Centre for International Agricultural Research, Canberra, Australia.

Pfündel, E., and W. Bilger. 1994. Regulation and possible function of the violaxanthin cycle. Photosynth Research 42:89-109.

Pinheiro, H., F. Damatta, A.M. Chaves, M. Loureiro, and C. Ducatti. 2005. Drought Tolerance is Associated with Rooting Depth and Stomatal Control of Water Use in Clones of Coffea canephora. Annals of Botany 96:101-108.

Plies, B.E., T. Kong, S. Schubert, and K. Mengel. 1995. Effect of water stress on plant growth, nitrogenase activity and nitrogen economy of four different cultivars of *Vicia faba* L Elsevier, Amsterdam, PAYS-BAS.

Purcell, L.C., and T.R. Sinclair. 1994. An osmotic hypothesis for the regulation of oxygen permeability in soybean nodules. Plant, Cell & Environment 17:837-843.

Purcell, L.C., and T.R. Sinclair. 1995. Nodule gas exchange and water potential response to rapid imposition of water deficit. Plant, Cell & Environment 18:179-187.

Rabha, B.K., and D.C. Uprety. 1998. Effects of Elevated CO_2 and Moisture Stress on *Brassica Juncea*. Photosynthetica 35:597-602.

Rainbird, R.M., J.H. Thorne, and R.W.F. Hardy. 1984. Role of Amides, Amino Acids, and Ureides in the Nutrition of Developing Soybean Seeds. Plant Physiology 74:329-334.

Ramirez-Vallejo, P., and J. Kelly. 1998. Traits related to drought resistance in common bean. Euphytica 99:127-136.

Ramos, M.L.G., A.J. Gordon, F.R. Minchin, J.I. Sprent, and R. Parsons. 1999. Effect of Water Stress on Nodule Physiology and Biochemistry of a Drought Tolerant Cultivar of Common Bean (*Phaseolus vulgaris* L.). Annals of Botany 83:57-63.

Raven, J.A., and G.D. Farquhar. 1990. The influence of N metabolism and organic acid synthesis on the natural abundance of isotopes of carbon in plants. New Phytologist 116:505-529.

Rebetzke, G., R. Richards, A. Condon, and G. Farquhar. 2006. Inheritance of Carbon Isotope Discrimination in Bread Wheat (*Triticum Aestivum* L.). Euphytica 150:97-106.

Regent Instruments Inc. 2011. WinRHIZO for root analysis: www.regentinstruments.com [Online].

Reynolds, J., and J. Chen. 1996. Modelling whole-plant allocation in relation to carbon and nitrogen supply: Coordination versus optimization: Opinion. Plant and Soil 185:65-74.

Reynolds, M., F. Dreccer, and R. Trethowan. 2007. Drought-adaptive traits derived from wheat wild relatives and landraces. Journal of Experimental Botany 58:177-186.

Ribas-Carbo, M., N.L. Taylor, L. Giles, S. Busquets, P.M. Finnegan, D.A. Day, H. Lambers, H.l. Medrano, J.A. Berry, and J. Flexas. 2005. Effects of Water Stress on Respiration in Soybean Leaves. Plant Physiology 139:466-473.

Ronis, D.H., D.J. Sammons, W.J. Kenworthy, and J.J. Meisinger. 1985. Heritability of Total and Fixed N Content of the Seed in Two Soybean Populations. Crop Science 25:1-4.

Rytter, R.M. 2005. Water Use Efficiency, Carbon Isotope Discrimination and Biomass Production of Two Sugar Beet Varieties Under Well-Watered and Dry Conditions. Journal of Agronomy and Crop Science 191:426-438.

Sall, K., and T.R. Sinclair. 1991. Soybean genotypic differences in sensitivity of symbiotic nitrogen fixation to soil dehydration. Plant and Soil 133:31-37.

Saranga, Y., I. Flash, and D. Yakir. 1998. Variation in Water-Use Efficiency and Its Relation to Carbon Isotope Ratio in Cotton. Crop Science 38:782-787.

Schubert, S., R. Serraj, E. Plies-Balzer, and K. Mengel. 1995. Effect of Drought Stress on Growth, Sugar Concentrations and Amino Acid Accumulation in N2-Fixing Alfalfa (*Medicago sativa*). Journal of Plant Physiology 146:541-546.

Serraj, R., T.R. Sinclair, and L.C. Purcell. 1999. Symbiotic N_2 fixation response to drought. Journal of Experimental Botany 50:143-155.

Serraj, R., P. Fleurat-Lessard, B. Jaillard, and J.J. Drevon. 1995. Structural changes in the innercortex cells of soybean root nodules are induced by short-term exposure to high salt or oxygen concentrations. Plant, Cell & Environment 18:455-462.

Serraj, R., S. Bona, L.C. Purcell, and T.R. Sinclair. 1997. Nitrogen accumulation and nodule activity of field-grown 'Jackson' soybean in response to water deficits. Field Crops Research 52:109-116.

Shaheen, R., and R.C. Hood-Nowotny. 2005. Effect of drought and salinity on carbon isotope discrimination in wheat cultivars. Plant Science 168:901-909.

Shearer, G., and D.H. Kohl. 1986. N_2-Fixation in Field Settings: Estimations Based on Natural ^{15}N Abundance. Functional Plant Biology 13:699-756.

Shenkut, A.A., and M.A. Brick. 2003. Traits associated with dry edible bean (*Phaseolus vulgaris* L.) productivity under diverse soil moisture environments. Euphytica 133:339-347.

Sheshshayee, M.S., H. Bindumadhava, R. Ramesh, T.G. Prasad, M.R. Lakshminarayana, and M. Udayakumar. 2005. Oxygen isotope enrichment ($\Delta^{18}O$) as a measure of time-averaged transpiration rate. Journal of Experimental Botany 56:3033-3039.

Siddique, K.H.M., S.P. Loss, K.L. Regan, and R. Jettner. 1999. Adaptation of cool season grain legumes in Mediterranean-type environments of south-western Australia. Australian Journal of Agricultural Research 50:375-387.

Siddique, K.H.M., K.L. Regan, D. Tennant, and B.D. Thomson. 2001. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy 15:267-280.

Siddique, M.R.B., A. Hamid, and M.S. Islam. 2000. Deought stress effects on water relations on wheat. Botanical Bulletin of Academia Sinica 41 35-39.

Signarbieux, C., and U. Feller. 2011. Non-stomatal limitations of photosynthesis in grassland species under artificial drought in the field. Environmental and Experimental Botany 71:192-197.

Silsbury, J.H. 1977. Energy requirement for symbiotic nitrogen fixation. Nature 267:149-150.

Sincik, M., B.N. Candogan, C. Demirtas, H. Buyukcangaz, S. Yazgan, and T. Goksoy. 2008. Degficit Irrigation of Soya Bean (*Glyine max* (L) Merr.) in a Sub-humid Climates Journal of Agronomy and Crop Science 194:200-205.

Sinclair, T.R. 1986. Water and nitrogen limitations in soybean grain production I. Model development. Field Crops Research 15:125-141.

Sinclair, T.R., and R. Serraj. 1995. Dinitrogen fixation sensitivity to drought among grain legume species. Nature 378 344.

Sinclair, T.R., and R.C. Muchow. 2001. System Analysis of Plant Traits to Increase Grain Yield on Limited Water Supplies. Agronomy Journal 93:263–270.

Sinclair, T.R., L.C. Purcell, C.A. King, C.H. Sneller, P. Chen, and V. Vadez. 2007. Drought tolerance and yield increase of soybean resulting from improved symbiotic N2 fixation. Field Crops Research 101:68-71.

Singh, V., E. Oosterom, D. Jordan, C. Messina, M. Cooper, and G. Hammer. 2010. Morphological and architectural development of root systems in sorghum and maize. Plant and Soil 333:287-299.

Smeal, D., and H. Zhang. 1994. Chlorophyll meter evaluation for nitrogen management in corn. Communications in Soil Science and Plant Analysis 25:1495-1503.

Soares-Cordeiro, A.S., S.P. Driscoll, T.K. Pellny, E. Olmos, M.C. ArrabaÇA, and C.H. Foyer. 2009a. Variations in the dorso-ventral organization of leaf structure and Kranz anatomy coordinate the control of photosynthesis and associated signalling at the whole leaf level in monocotyledonous species. Plant, Cell & Environment 32:1833-1844.

Soares-Cordeiro, A.S., A.E. Carmo-Silva, A. Bernardes da Silva, J. Marques da Silva, A.J. Keys, and M.C. Arrabaça. 2009b. Effects of rapidly imposed water deficit on photosynthetic parameters of three C4 grasses. Photosynthetica 47:304-308.

Sponchiado, B.N., J.W. White, J.A. Castillo, and P.G. Jones. 1989. Root Growth of Four Common Bean Cultivars in Relation to Drought Tolerance in Environments with Contrasting Soil Types. Experimental Agriculture 25:249-257.

Sponchiado BN, JW White, J.C. and, and P. Jones. 1989. Root growth of four common bean cultivars in relation to drought tolerance in environments with contrasting soil types. Experimental Agriculture 25:249–257.

Steele, K.A., D.S. Virk, R. Kumar, S.C. Prasad, and J.R. Witcombe. 2007. Field evaluation of upland rice lines selected for QTLs controlling root traits. Field Crops Research 101:180-186.

Streeter, J.G. 2003. Effects of drought on nitrogen fixation in soybean root nodules. Plant, Cell & Environment 26:1199-1204.

Subbarao, G.V., C. Johansen, A.E. Slinkard, R.C. Nageswara Rao, N.P. Saxena, Y.S. Chauhan, and R.J. Lawn. 1995. Strategies for Improving Drought Resistance in Grain Legumes. Critical Reviews in Plant Sciences 14:469-523.

Tefera, H. 2011. Breeding for Promiscuous Soybeans at IITA, Soybean - Molecular Aspects of Breeding, Aleksandra Sudaric (Ed.), InTech. .

Teulat, B., O. Merah, and D. This. 2001. Carbon Isotope Discrimination and Productivity in Field-Grown Barley Genotypes. Journal of Agronomy and Crop Science 187:33-39.

Tezara, W., V.J. Mitchell, S.D. Driscoll, and D.W. Lawlor. 1999. Water stress inhibits plant photosynthesis by decreasing coupling factor and ATP. Nature 401:914-917.

Tezara, W., V. Mitchell, S.P. Driscoll, and D.W. Lawlor. 2002. Effects of water deficit and its interaction with CO_2 supply on the biochemistry and physiology of photosynthesis in sunflower. Journal of Experimental Botany 53:1781-1791.

Tezara, W., D. Martinez, E. Rengifo, and A.N.A. Herrera. 2003. Photosynthetic Responses of the Tropical Spiny Shrub *Lycium nodosum* (Solanaceae) to Drought, Soil Salinity and Saline Spray. Annals of Botany 92:757-765.

Thavarajah, D., and R.A. Ball. 2006. Drought-induced changes in free amino acid and ureide concentrations of nitrogen-fixing chickpea. Canadian Journal of Plant Science 86:149-156.

Thomas, M.J. Robertson, S. Fukai, and M.B. Peoples. 2004. The effect of timing and severity of water deficit on growth, development, yield accumulation and nitrogen fixation of mungbean. Field Crops Research 86:67-80.

Thomson, B.D., K.H.M. Siddique, M.D. Barr, and J.M. Wilson. 1997. Grain legume species in low rainfall mediterranean-type environments I. Phenology and seed yield. Field Crops Research 54:173-187.

Trachsel, S., S. Kaeppler, K. Brown, and J. Lynch. 2011. Shovelomics: high throughput phenotyping of maize (*Zea mays* L.) root architecture in the field. Plant and Soil 341:75-87.

Troughton, J.H., K.A. Card, and C.H. Hendy. 1974. Photosynthetic pathways and carbon isotope discrimination by plants. Carnegie Inst. Wash,Yearbook 73,768-180

Tschoep, H. 2010. The response of growth and primary metabolism to a mild but sustained nitrogen limitation in Arabidopsis thaliana. PhD dissertation. Mathematisch-Naturwissenschaftliche Fakultät, University of Potsdam, Germany.

Turner, L., and H . Gibson. 1980. Measurement of nitrogen fixation by indirect means. In Methods for Evaluating Biological Nitrogen Fixation. Edited by F. J. Bergersen. Chichester: Wiley:111 - 138.

Turner, L., and H. Gibson. 1980. Measurement of nitrogen fixation by indirect means. In Methods for Evaluating Biological Nitrogen Fixation.(ed. F.J. Bergersen),pp.111-138 Wiley, Chichester.

Turner, N.C. 1982. The role of shoot characteristics in drought tolerance of crop plants. In: Drought tolerance in crop with emphasis on rice. International rice Research Institute, Los Banos, Manila, Philippines, pp.115-134.

Turner, N.C., and N.C. Brady. 1986. Crop Water Deficits: A Decade of Progress, p. 1-51 Advances in Agronomy, Vol. Volume 39. Academic Press.

Turner, N.C., G.C. Wright, and K.H.M. Siddique. 2001. Adaptation of grain legumes (pulses) to water-limited environments, p. 193-231 Advances in Agronomy, Volume 71. Academic Press.

Uddling, J., J. Gelang-Alfredsson, K. Piikki, and H. Pleijel. 2007. Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. Photosynthesis Research 91:37-46.

Udensi, O., E.V. Ikpeme, A.A. Markson, E.A.B. Edu, E.J. Umana, and I.S. Urua. 2010. Selection of soybean genotypes using morphological markers International Journal of Current Research 7:005-008.

Unkovich, M.J., and J.S. Pate. 2000. An appraisal of recent field measurements of symbiotic N_2 fixation by annual legumes. Field Crops Research 65:211-228.

Unkovich, M.J., J.S. Pate, P. Sanford, and E.L. Armstrong. 1994. Potential precision of the $\delta^{15}N$ natuural abundance method in field estimates of nitrogen fixation by crop and pasture legumes in south-west Australia. Australian Journal of Agricultural Research 45:119-132.

USDA. 2011. http://soils.usda.gov/ [Online].

Valles-De La Mora, B., G. Cadisch, and A. Aluja-Schunemann. 2003. Comparación de metodologías de isótopos para evaluar fijación de n atmosférico y su destino en suelos y plantas. Agrociencia 37:117-128.

Van Heerden, P.D.R., M. De Beer, D.J. Mellet, H.S. Maphike, and W. Foit. 2007. Growth media effects on shoot physiology, nodule numbers and symbiotic nitrogen fixation in soybean. South African Journal of Botany 73:600-605.

Van Heerden, P.D.R., G. Kiddle, T.K. Pellny, P.W. Mokwala, A. Jordaan, A.J. Strauss, M. de Beer, U. Schluter, K.J. Kunert, and C.H. Foyer. 2008. Regulation of Respiration and the Oxygen Diffusion Barrier in Soybean Protect Symbiotic Nitrogen Fixation from Chilling-Induced Inhibition and Shoots from Premature Senescence. Plant Physiol. 148:316-327.

Vance, C.P., K.L.M. Boylan, C.A. Maxwell, G.H. Heichel, and L.H. Leland. 1985. Transport and Partitioning of CO_2, Fixed by Root Nodules of Ureide and Amide Producing Legumes. Plant Physiology 78:774-778.

Vassey, T.L., and T.D. Sharkey. 1989. Mild Water Stress of Phaseolus vulgaris Plants Leads to Reduced Starch Synthesis and Extractable Sucrose Phosphate Synthase Activity. Plant Physiology 89:1066-1070.

Venkateswarlu, B., N. Saharan, and M. Maheswari. 1990. Nodulation and N_2 (C_2H_2) fixation in cowpea and groundnut during water stress and recovery. Field Crops Research 25:223-232.

Voisin, A.S., C. Salon, C. Jeudy, and F.R. Warembourg. 2003. Root and Nodule Growth in *Pisum sativum* L. in Relation to Photosynthesis: Analysis Using 13C-labelling. Annals of Botany 92:557-563.

Vos, J., P.E.L.v.d. Putten, and C.J. Birch. 2005. Effect of nitrogen supply on leaf appearance, leaf growth, leaf nitrogen economy and photosynthetic capacity in maize (*Zea mays* L.). Field Crops Research 93:64-73.

Walsh, K.B., M.J. Canny, and D.B. Layzell. 1989. Vascular transport and soybean nodule function: II. A role for phloem supply in product export. Plant, Cell & Environment 12:713-723.

Wani, S.P., O. P. Rupela, and K. K. Lee. 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. Plant and Soil 174:29-49.

Warren, C.R. 2008. Stand aside stomata, another actor deserves centre stage: the forgotten role of the internal conductance to CO. Journal of Experimental Botany 59:1475-1487.

White, D.S., M.J. Bell, and G.C. Wright. 1996 The potential to use carbon isotope discrimination as a selection tool to improve water use efficiency in soybean. Proceeding of the 8th Australian agronomy conference, Toowoomba, Queensland.

White, J.W., and S.P. Singh. 1991a. Breeding for Addaption to drought. In: (Schoonhoven, and A. Voysest, O., eds.) Common beans: research for crop improvement C.A.B. International in association with Centro Internacional de Agricultura Tropical.

White, J.W., and J.s.A. Castillo. 1991. Evaluation of Diverse Shoot Genotypes on selected Root Genotypes of Common Bean under Soil Water Deficits. Crop Science 32:762-765.

White, J.W., and S.P. Singh. 1991b. Sources and inheritance of earliness in tropically adapted indeterminate common bean. Euphytica 55:15-19.

White, J.W., J.A. Castillo, and J. Ehleringer. 1990. Associations Between Productivity, Root Growth and Carbon Isotope Discrimination in (*Phaseolus vulgaris* L.) Under Water Deficit. Functional Plant Biology 17:189-198.

Whitmore, J.S. 2000. Drought Management on Farmland Springer.

Wilhite, D.A., and M.H. Glantz. 1985. Understanding: the Drought Phenomenon: The Role of Definitions. Water International 10:111-120.

Wilson, J.B. 1988. A Review of Evidence on the Control of Shoot: Root Ratio, in Relation to Models. Annals of Botany 61:433-449.

Wortmann, C.S., R.A. Kirkby, C.A.E. and, and D.J. Allen. 1998. Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa . Cali, Colombia: Centro Internacional de Agricultura Tropical. CIAT publication: no. 297.

Xiong, L., R.-G. Wang, G. Mao, and J.M. Koczan. 2006. Identification of Drought Tolerance Determinants by Genetic Analysis of Root Response to Drought Stress and Abscisic Acid. Plant Physiology 142:1065-1074.

Yadav, R., B. Courtois, N. Huang, and G. McLaren. 1997. Mapping genes controlling root morphology and root distribution in a doubled-haploid population of rice. TAG Theoretical and Applied Genetics 94:619-632.

Yamamoto, A., T. Nakamura, J.J. Adu-Gyamfi, and M. Saigusa. 2002. Relationship between chlorophyll content in leaves of sorghum and pigeon pea determined by extraction method by chlorophyll meter (SPAD-502) Journal of Plant Nutrition 25:2295-2301.

Yoneyama, T., and T. Ohtani. 1983. Variations of Natural 13C Abundances in Leguminous Plants. Plant and Cell Physiology 24:971-977.

Yordanov, I., D. Stefanov, V. Krasteva, M. Gourmanova, and V. Goltsev. 2012. Drought stress responses in plants - molecular biology, physiology and agronomical aspects 4:7-20.

Zacharisen, M.H., M.A. Brick, A.G. Fisher, J.B. Ogg, and J.R. Ehleringer. 1999. Relationships between productivity and carbon isotope discrimination among dry bean lines and F_2 progeny. Euphytica 105:239-250.

Zahran, H.H. 1999a. Rhizobium-Legume Symbiosis and Nitrogen Fixation under Severe Conditions and in an Arid Climate. Microbiology and Molecular Biology Reviews 968–989.

Zahran, H.H. 1999b. Rhizobium-Legume Symbiosis and Nitrogen Fixation under Severe Conditions and in an Arid Climate. Microbiology and Molecular Biology Reviews 63:968-989.

Zhang, X., N. Wu, and C. Li. 2005. Physiological and growth responses of *Populus davidiana* ecotypes to different soil water contents. Journal of Arid Environments 60:567-579.

Zhao, J., J. Fu, H. Liao, Y. He, H. Nian, Y. Hu, L. Qiu, Y. Dong, and X. Yan. 2004. Characterization of root architecture in an applied core collection for phosphorus efficiency of soybean germplasm. Chinese Science Bulletin 49:1611-1620.

Zhu, J.-K. 2001. Cell signaling under salt, water and cold stresses. Current Opinion in Plant Biology 4:401-406.

Zhu, J.-K. 2002. Salt and Drought Stress Signal Transduction in Plants. Annual Review of Plant Biology 53:247-273.

Zhu, X.-G., S.P. Long, and D.R. Ort. 2010. Improving Photosynthetic Efficiency for Greater Yield. The Annual Review of Plant Biology 61:235-261.

APPENDIX

Appendix 1: Analysis of variance comparisons of the effects of drought on photosynthetic CO_2 assimilation (A), stomatal conductance (G), Fv/Fm ratios and intracellular CO_2 concentrations (Ci) in the soybean cultivars: Prima 2000, A-5409RG and Jackson. Data for days 0, 7, 14 and 18 of the experiment were used in this analysis.

Variation	d.f.	Means square			
		A	G	Fv/Fm	Ci
Cultivar (C)	2	20.09 *	6.74 **	0.070 **	15272.4 **
Drought (D)	1	1065.98 **	68.12 **	0.091 **	376790.8 **
C*D	2	63.98 *	4.95 **	0.0156 *	1878.6 ns
Experimental error	117	5.88	0.244	0.002	1536.4
Total d.f.	122				

* $P < 0.05$, and ** $P < 0.01$, d.f. degrees of freedom

Appendix 2: Analysis of variance for six common bean lines on CO_2 assimilation (µmol $m^{-2}s^{-1}$) **(A)**, stomatal conductance (mmol $m^{-2}s^{-1}$) (G), leaf, stem and root dry mass (DW), nodule fresh mass (FW) and symbiotic nitrogen fixation (SNF/g of nodules) estimated by acetylene reduction assay, under drought and well- watered conditions for 18 days.

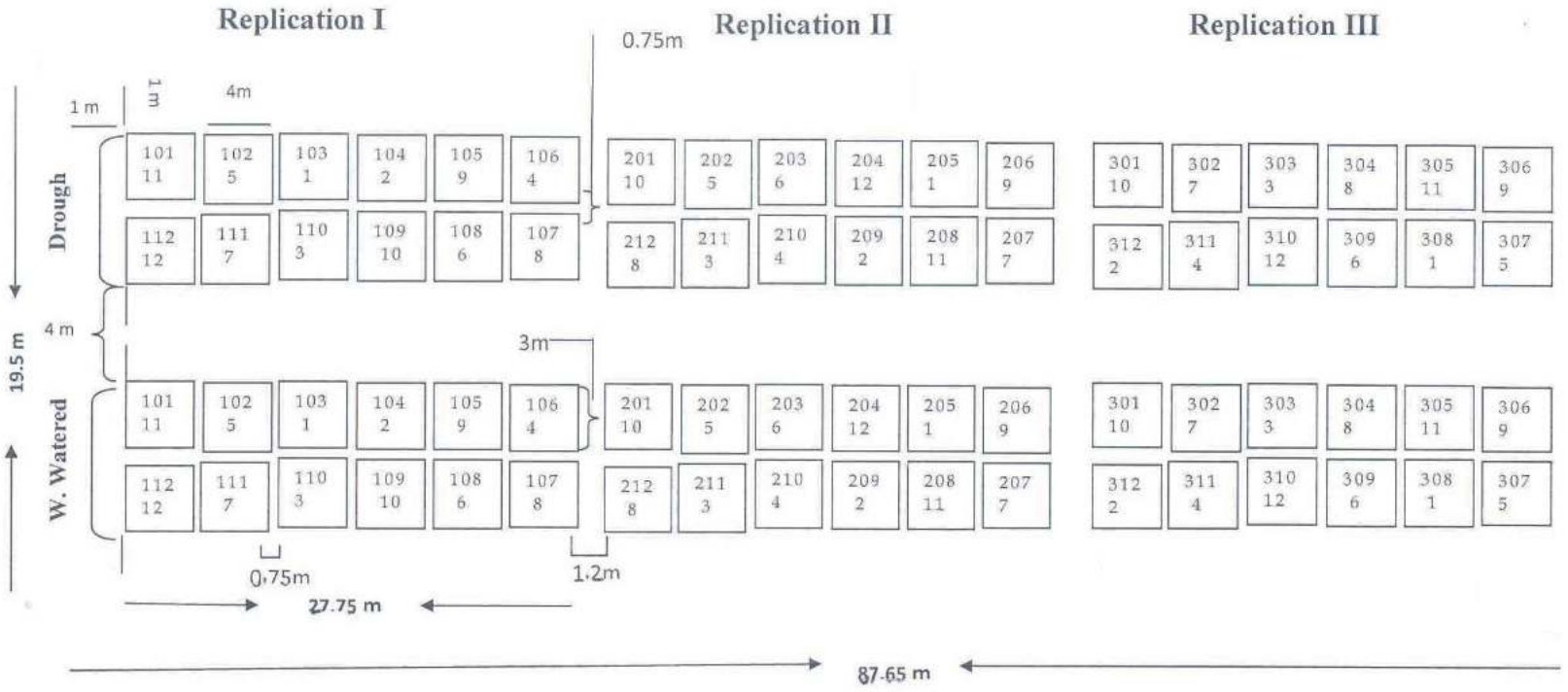
Variation	d.f.	Means square						
		A	G	Leaf DW	Stem DW	Root DW	Nodule FW	SNF
Well-watered								
Line	5	17.761	210154	1.13	2.280	1.768	1.34	1.954
P-value		0.027	0.012	0.003	0.008	<.0001	<.0001	<.0001
Significance		*	*	*	**	**	ns	**
Drought								
Line	5	51.253	79162	1.032	1.10	5.024	0.755	1.425
P-value		0.037	0.043	0.004	<.0001	0.002	0.0465	0.0067
Significance		*	*	**	**	**	*	**
Exp. Error	84	20.64	43847.1	0.276	0.184	1.223	0.292	0.357
Total	89							

* and ** indicates significance at $P \leq 0.05$, and 0.01, respectively, ns = non-significant

Appendix 3: List of treatments and randomization of bean lines in a randomized complete block design with field layout

Treatment no.	Lines	Replications		
		I	II	III
1	BT _6-1-1	103	205	308
2	BT _34-1-1	104	209	312
3	BT _51-1-1	110	211	303
4	BT _147-3	106	210	311
5	DOR 364	102	202	307
6	BAT 477	108	203	309
7	DOR 364-NN	111	207	302
8	BAT 477-NN	107	212	304
9	A5409RG	105	206	306
10	Jackson	109	201	301
11	Prima 2000	101	208	305
12	PAN 185	112	204	310

101 -112, 201 -212 and 301-312, represents plot number for replication one, two and three respectively.



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Appendix 4: Analysis of variance for nine bean lines for root morphology traits under drought and well-watered conditions. Exposure to drought was for one month using four replicates from each treatment for acquired soil core up to 60 cm soil depth and the root image was taken by a root scanner and subsequent analysis was made by using the winRHIZO 2008a software.

		Means square				
Source of variation	**Df**	**Root length (cm)**	**Surface area (cm^2)**	**Root volume (cm^3)**	**Root tips**	**Average diameter (mm)**
Drought						
Lines	8	12013.8	189.20	0.022	101629.6	0.0214
Error	168	5115.7	73.34	0.0079	47978	0.0135
Total	176					
P-value		0.0229	0.0111	0.0062	0.0366	0.1348
Significance		*	*	**	*	ns
Well watered						
Lines	8	10111.23	115.36	0.009	63570.5	0.03203
Error	145	8292.2	107.20	0.0099	76150.8	0.0161
Total	153					
P-value		0.2917	0.383	0.518	0.5734	0.0512
Significance		ns	ns	ns	ns	ns

*and **indicates significance at P<0.05 and 0.01 respectively, ns= non-significant (P>0.05), Df = degree of freedom.

Appendix 5: Analysis of variance for the root architectural traits of nine bean lines under well watered and drought conditions for 4 weeks. The data represents six individual plants per plot (18 plants per bean lines) for each water regime.

Water regime	Root architecture parameters										
	Whorl			Tap root		Basal root			Adventurous root		
	No. of Whorl	1st Whorl angle	2nd Whorl angle	Width (mm)	Branching density	Number	Width (mm)	Branching density	Number	Width (mm)	Branching density
Well-watered											
Means square	0.364	557.49	451.24	2.111	29.22	6.55	0.339	35.06	52.07	0.39	35.23
P-value	0.055	0.227	0.0239	0.063	0.095	0.012	0.11	0.005	0.021	0.031	0.034
Significance	ns	*	*	ns	ns	*	ns	*	*	*	*
Drought											
Means square	0.186	482.68	379.76	1.079	40.06	6.0	0.39	27.65	0.349	1.079	47.46
P-value	0.426	0.006	0.047	0.195	0.001	0.043	0.196	0.0395	0.001	0.195	<0.0001
Significance	ns	**	*	ns	**	*	ns	*	ns	**	**

*and **indicates significance at P ≤ 0.05 and 0.01 respectively, ns= non-significant

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Appendix 6: Two ways ANOVA for nine common bean lines for biomass at flowering (Fl) and mid pod filling (MPF) stage for experimental variation of: lines (L), water treatment (W) and their interaction (L*W) for plants grown under field condition. The result represents for the plants exposed after 4 weeks drought stress.

Variation	d.f.	Means square				d.f.	Means square
		Total shoot dry mass at Fl (g)	Leaf dry mass at MPF (g)	Pod dry mass at MPF(g)	Total Shoot dry mass at MPF (g)		Seed yield (kg/ha)
Lines (L)	8	17.53 **	34.69 **	26.06 **	133.16 **	8	1468078 **
Water (W)	1	127.62 **	209.25 **	76.54 **	614.71 **	1	8523571 **
L*W	8	7.91 **	6.62 *	4.19 *	25.80 *	8	160518 *
Exp. error	90					36	
Total d.f.	107					53	

*and **indicates significance at P<0.05 and 0.01 respectively, d.f. = degree of freedom, Exp. = Experimental

Appendix 7: Analysis of variance for nine common bean lines for shoot and seed CID and C% as well as shoot C:N ratio under well-watered and drought conditions. Shoot samples were harvested after one month of drought exposure, at 30 days after planting.

Source of Variation	**DF**	**Shoot** CID	**Seed** CID	**Shoot C%**	**Seed C%**	**Shoot C:N ratio**
Well-watered						
Mean square						
Lines	8	0.533	3.8	4.729	1.187	49.230
Error	18	0.196	0.921	2.362	0.140	11.652
Total	26					
P-value		0.037	0.006	0.106	<.0001	0.005
Significance		*	**	ns	**	**
Drought						
Mean square						
Lines	8	0.421	0.918	1.3778	0.4964	56.467
Error	18	0.090	0.348	1.814	0.177	5.289
Total	26					
P-value		0.003	0.042	0.641	0.033	<.0001
Significance		**	*	ns	*	**

*and **indicate significance at P ≤ 0.05 and 0.01 respectively, ns= non significant, DF= degree of freedom

Appendix 8: Analysis of variance of seven common bean lines for shoot and seed $\delta^{15}N$ and %N as well as for calculated nitrogen derived from the atmosphere (Ndfa), plant N and fixed N (estimated from shoot %N,) (from 2.25 m^2 area) under well-watered and drought conditions. Shoot samples were harvested after one month of drought exposure, 30 days after planting.

Source of Variation	**DF**	**Shoot $\delta^{15}N$**	**Seed $\delta^{15}N$**	**Shoot %N**	**Seed %N**	**Ndfa**	**Plant N**	**Fixed N**
Well-watered								
Means square								
Lines	8	3.2471	5.6897	1.079	1.441	0.90	8.031	4.389
Error	18	1.083	0.240	0.202	0.117	0.982	1.023	1.257
Total	26							
P-value		0.025	<.0001	0.002	<.0001	0.511	0.002	0.025
Significance		*	**	**	**	ns	**	*
Drought								
Means square								
Lines	8	4.024	2.344	0.488	0.759	1.647	5.251	4.713
Error	18	0.388	0.80	0.071	0.219	0.460	0.238	0.214
Total	26							
P-value		<.0001	0.028	0.0003	0.014	0.023	<.0001	<.0001
Significance		**	*	**	*	*	**	**

*and **indicate significance at P < 0.05 and 0.01 respectively, ns= non-significant, DF= degree of freedom.

Appendix 9: Two way analysis of variance for for three soybean cultivars for root morphology traits for plants grown under well-watered and drought conditions. The data was obtained from root image taken by a root scanner and analysis made by using the winRHIZO 2008a software after 4 weeks of drought stress exposure.

Variation	d.f.	Means square			
		Root length (cm)	Root surface area (cm^2)	Root volume (cm^3)	Root tips
Cultivar (C)	2	13781.36 *	195.04 *	0.0262 *	89634.2 ns
Water (W)	1	22935.14 *	226.54 ns	0.0115 ns	327445.2 **
C*W	2	17227.88 *	380.03 **	0.0535 **	108768.0 *
Exp. error	116				
Total d.f.	121				

*and **indicates significance at P<0.05 and 0.01 respectively, ns = non-significant, d.f. = degree of freedom, Exp. = Experimental

Appendix 10: Two way analysis of variance for three soybean cultivars for biomasses at flowering (Fl) as well as mid pod filling stage (MPF) and seed yield for plants grown under field conditions in two water regimes (well-watered and drought conditions) after 4 weeks of drought stress exposure.

Variation	d.f.	Means square							
		Leaf dry mass at Fl (g)	**Stem dry mass at Fl (g)**	**Total dry mass at Fl (g)**	**Leaf dry mass at MPF(g)**	**Stem dry mass at MPF (g)**	**Pod dry mass at MPF (g)**	**Total dry mass at MPF (g)**	**Seed yield (kg/ha)**
Cultivar (C)	2	10.33 **	4.98 **	29.26 **	108.73 **	58.74 **	22.61 **	491.01 **	3590276 **
Water (W)	1	35.56 **	20.69 **	110.50 **	83.33 **	111.37 **	83.30 **	829.92 **	10666164 **
C*W	2	1.17 *	0.018 ns	1.17 ns	8.74 *	5.56 ns	14.62 **	57.67 *	1554792 **
Exp. error	116								
Total d.f.	121								

*and **indicates significance at P<0.05 and 0.01 respectively, ns = non-significant, d.f. = degree of freedom, Exp. = Experimental

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