EFFECT OF DROUGHT STRESS ON GROWTH OF UPLAND RICE

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

HORTICULTURE AND LANDSCAPING PROGRAMME
FACULTY OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2017

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN TESIS

JUDUL: EFFECT OF DROUGHT STRESS ON GROWTH OF UPLAND RICE

IJAZAH: Sarjana Muda Sains Pertanian dengan Kepujian (HG35 Hortikultur dan Landskap)

SAYA: LIM SIEW LIAN **SESI PENGAJIAN:** 2013-2017

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ACKNOWLEDGEMENT

I would like to take this opportunity to express my gratefulness to God for all the blessings that He has bestowed upon me and for giving the wisdom and strength to complete my final year project successfully.

I would also like to convey my heartfelt gratitude towards my parents and siblings, who have supported me both through their prayers and also mental support to work my best.

My sincere thanks goes to my supervisor, Mr. Lum Mok Sam who has guided me patiently throughout the project and has given me constant support and motivation to strive for excellence. He has been sharing with me immense of knowledge and experiences which are vital for this research and problem-solving.

Furthermore, I would like to thank the lab assistants of Faculty of Sustainable Agriculture, Miss Nurul Syakina binti Marli and Mr. Mohd. Rohizan Basir for their help and kindness. They have offered technical operation guides which have aided me in completing the thesis.

Lastly, I would like to thank my fellow course mates, Miss Chee Hoyau, Miss Cheong Kah Kei, Miss Pang Yi Ling, Mr. Jonathan Goh Jia En, Mr. Calister Jurian Clarence and Miss Louria Sunta Meyu for their supports and helps throughout the study.

May God continue to bless all of you for all the help that I have received. Thank you.

ABSTRACT

One of the main problems of upland rice cultivation and production is drought stress. In this study, the growth performance of upland rice variety Mutiara was compared in different levels of drought stress under field condition. The experimental design used was Completely Randomized Design (CRD) with 10 replicates for each treatment. The treatments were 100% field capacity (control), 75% field capacity, 50% field capacity and 25% field capacity. The data was analysed using one way ANOVA and LSD was applied to compare means. No significant differences ($p>0.05$) were observed in plant height, leaf length, leaf width, leaf number, root length, root dry weight, shoot dry weight, root-shoot ratio, chlorophyll a, chlorophyll b, total chlorophyll, carotenoid, relative water content and proline content. However, the tiller number of treatments of FC 100%, FC 75% and FC 50% were significantly higher ($p<0.05$) than tiller number of treatment of FC 25%. The LAI of treatment of FC 50% was significantly lower ($p<0.05$) than treatment of FC 75%. It was concluded that FC 75% was sufficient for irrigation as there were no significant differences observed for any components when compared to the controlled treatment, FC 100%. Further research is needed to study the drought stress effect on other upland rice varieties.

KESAN KEMARAU PADA PERTUMBUHAN PADI HUMA

ABSTRAK

Salah satu masalah utama penanaman dan pengeluaran padi huma adalah masalah kemarau. Dalam kajian ini, prestasi pertumbuhan beras Mutiara dibandingkan di bawah tahap kemarau yang berbeza. Rekabentuk eksperimen yang telah diguna adalah CRD dengan 10 replikasi untuk setiap rawatan. Rawatan yang telah diaplikasi adalah 100% kapasiti padang (terkawal), kapasiti padang 75%, kapasiti padang 50% dan kapasiti padang 25%. Rawatan telah diterapkan pada peringkat pembentukan tangkai untuk selama 20 hari. Data telah dianalisis menggunakan ANOVA satu hala dan LSD telah diguna untuk membandingkan min. Tiada perbezaan yang signifikan ($p>0.05$) diperhatikan dalam ketinggian tumbuhan, panjang daun, lebar daun, bilangan daun, panjang akar, berat kering akar, berat kering pucuk, nisbah akar-pucuk, klorofil a, klorofil b, jumlah klorofil, karotenoid, kandungan air relatif dan kandungan proline. Walau bagaimanapun, bilangan anakan padi untuk rawatan FC 100%, FC 75% dan FC 50% adalah lebih tinggi ($p <0.05$) daripada bilangan anakan padi untuk rawatan FC 25%. LAI rawatan FC 50% adalah jauh lebih rendah ($p <0.05$) berbanding rawatan FC 75%. Kesimpulan telah dibuat bahawa FC 75% adalah mencukupi untuk pengairan kerana tidak ada perbezaan yang ketara diperhatikan bagi mana-mana komponen berbanding rawatan dikawal, FC 100%. Kajian lanjutan diperlukan untuk mengkaji kesan kemarau pada varieti padi huma yang lain.

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µm	Micrometre
µmole g^{-1} FW	Micromole per gram of fresh weight
^{o}C	Degree Celsius
ABA	Abscisic acid
ANOVA	Analysis of variance
AOSA	Association Official Seed Analysts
$BaCl_2$	Barium Chloride
$BaCl_2.2H_2O$	Barium Chloride Dihydrate
CEC	Cation exchange capacity
Chl_a	Chlorophyll a
Chl_b	Chlorophyll b
CHN	Carbon, hydrogen and nitrogen
cm	Centimetre
cmolc kg^{-1}	Centimoles per kilogram
CO_2	Carbon dioxide
CRD	Completely Randomized Design
C_{x+c}	Total carotenoid
DAE	Days after emergence
DOA	Department of Agriculture
DW	Dry weight
FC	Field capacity
FSA	Faculty of Sustainable Agriculture
FW	Fresh weight
g	Gram
ha	Hectare
ha^{-1}	Per hectare
HCl	Hydrochloric acid
HMP	Sodium Hexameraphosphate
IRRI	International Rice Research Institute
K_2O	Potassium oxide
kg	Kilogram
LAI	Leaf area index
LSD	Least significant difference
m	Meter
M	Molar
m^2	square meter
meq	Milliequivalent
mg	Milligram
$MgSO_4.7H_2O$	Magnesium Sulfate Heptahydrate
ml	Millilitre
mm	Millimetre
mM	Millimolar
MOEF	Ministry of Environment and Forest
N	Normal
NAP3	National Agricultural Policy 3
nm	Nanometre
P	Phosphorus
P_2O_5	Phosphorous Pentoxide
ppm	Parts per million

PSII	Photosystem II
QTLs	Quantitative trait loci
RM	Ringgit Malaysia
rpm	Revolutions per minute
RWC	Relative water content
$SnCl_2.2H_2O$	Stannous chloride
SSL	Self-sufficiency level
TC	Total chlorophyll
TW	Turgid weight
USDA	United States Department of Agriculture
WARDA	Africa Rice Centre
WUE	Water use efficiency

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3.1 Field Capacity 23

$$FC = \frac{\text{mass of water}}{\text{oven-dried mass of soil}} \times 100\%$$

3.2 Percentage of sand 25

$$\text{Sand \%} = \frac{\text{Oven dry soil mass} - (\text{Rsand} - \text{RC1})}{\text{Oven dry soil mass}} \times 100\%$$

Where:
Rsand = Hydrometer reading for sand;
RC1 = First hydrometer reading for blank solution

3.3 Percentage of clay 25

$$\text{Clay \%} = \frac{\text{Rclay} - \text{RC2}}{\text{Oven dry soil mass}} \times 100\%$$

Where:
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Where:
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FW = Fresh weight;
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Where:
A_{662} = absorbance at the wavelength 662 nm
A_{644} = absorbance at the wavelength 644 nm

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Where:

A_{662} = absorbance at the wavelength 662 nm

A_{644} = absorbance at the wavelength 644 nm

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$\text{TC} = \text{Chl}_a + \text{Chl}_b$

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Where:
A_{470} = absorbance at the wavelength 470 nm

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CHAPTER 1

INTRODUCTION

1.1 Rice

Rice (*Oryza sativa*), is the second most widely grown cereal crop and is the staple food for more than half the world's population. Rice is depended for its food calories and protein especially in developing countries. Based on the availability of land and water, rice can be grown on lowland or upland. Unlike the lowland rice that is planted in flooded soil, cultivation of upland rice is on the dryland which mostly relies on rain-fed irrigation.

In Malaysia, more than 100,000 farmers depend on rice production for their livelihoods and many more are working in rice-related industry. In 2013, the total rice-planted area in Malaysia for all seasons is 647,332 hectare (ha) producing 1,685,236 metric tonnes. Among the total rice production, the wetland rice production is 1,648,414 tonnes and the dryland rice production is 36,822 metric tonnes (DOA, 2014). As seen from the data, the production of dryland rice (lowland and upland) is much lower.

During the implementation of National Agricultural Policy 3 (NAP3), the self-sufficiency level (SSL) of rice in Malaysia is 71% (Malaysia, 1998). The SSL is used as a proxy to indicate the level of food security of rice. In 2013, the total import of rice in Malaysia is 886,820 metric tonnes which is worth Ringgit Malaysia (RM) 1,583,778,000, whereas the export of rice is only 10,776 metric tonnes with the worth of RM 20,975,000.

In National Agro-food Policy that is intending to replace NAP3, it did not aim for full sufficiency of SSL as Malaysia is a high cost producer of rice. Indirectly, this data shows that Malaysia is still facing many challenges in achieving full sufficiency of rice production. Some of the challenges of rice production in Malaysia are increase of food price, climate change, population growth and resources scarcity.

1.2 Upland Rice

The upland rice has traditionally suffered from drought and infertile soils, weeds and plant diseases. They are adapted to the adverse environment and are able to produce grains that meet local needs. Compared to wetland rice, upland rice has significantly low yield and they are account for only 5% of world rice production. According to Department of Agriculture (DOA) (2014), in 2013, the average yield for dryland paddy in Malaysia is only 900 kilogram (kg) per hectare (ha^{-1}), which is much lower compared to the average yield of wetland paddy which is 4,211 kg ha^{-1}.

Even though they have low yield, they are able to thrive in such poor condition. This characteristic makes them the target of many researchers to study about their traits hoping that this can increase their yield or to apply this trait on commercial rice.

1.3 Drought Stress

Drought is one of the most important limiting abiotic factors for crop production and is becoming an increasingly severe problem in many global regions. It can occur at any stage during the rice growing season due to inadequate irrigation, uneven distribution of rainfall, variation in the rainfall patterns from one year to another or inadequate rainfall in large areas (Zhang, 2007). It can influence the grain production and quality and with global climate change and increasing population, the situation is made worse. However, water is needed in every phase of plant growth. Rice as a paddy field crop is particularly susceptible to drought stress which will affect the yield and quality produced.

For upland rice cultivation, drought is the common issue. Though they have been widely recognized to be more drought resistant than wetland rice, it is important to study how they react to drought stress and its effect on them.

1.4 Justification

From all the data shown, the rice production in Malaysia is still unable to reach full sufficiency level and is unable to ensure the national food security. The high amount of rice imports only show the severity of the problem. Additionally, there are more challenges such as the climate change, population growth and resources scarcity which makes the food production more challenging in this country.

Even though upland rice have low yield potential, they have shown greater drought tolerance and yield stability. Upland rice has the potential of improving the national food security. In Malaysia, the urbanization and intensification of land use for cash crop has caused the issue of resources scarcity in terms of availability of fertile land. The cultivation of upland rice is able to alleviate the land scarcity issues as it can be planted on hilly or mountainous area. Additionally, cultivation of upland rice does not require flooding of water or frequent irrigation which can ease the problem of water resources problem due to climate change. It can also reduce the rice production cost as less water is needed for irrigation.

By studying the effect of drought stress on upland rice, we are able to observe how the plants react to drought and the mechanism involved in resisting drought. If a rice variety manifests itself in satisfactory grain yield under drought stress, it is deemed viable and economical for cultivation. This will also serve as the cue to further improve the upland rice in particular for breeding drought-tolerant and high-yield-potential upland rice variety.

Under treatment of different levels of drought stress, we will be able to determine minimum water required to produce potential yield for upland rice variety. Then, farmer can determine the best time to plant this variety according to the rainfall pattern of the region.

As the upland rice has shown so much potential, it is important to study about it to unleash the benefits it can bring to the rice production industry in Malaysia and improve the national food security. Furthermore, the studies of upland rice is still at its infancy and there are still a lot to be known about.

1.5 Objective

The objective of this research was to assess the effect of different drought stress levels on growth of upland rice.

1.6 Hypothesis

H_0: There is no significant difference between different levels of drought stress in the growth of upland rice grown on Silabukan soil.

H_A: There is significant difference between different levels of drought stress in the growth of upland rice grown on Silabukan soil.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Rice

Rice, also known as *Oryza sativa L.*, is the primary source of food and calories for about half of the world population (Khush, 2005). It is mostly grown and consumed in Asia, where rice is grown in 135 million ha with an annual production of 516 million tonnes (Roy and Misra, 2002).

In a study conducted by Oka and Morishima (1982), they suggested that Asian rice, *Oryza sativa*, *indica* and *japonica* were domesticated from *Oryza rufipogon*, a wild rice species. The domestication of the rice can be dated back to 8200 to 13500 years ago. The origin of rice domestication is still being debated by archaeologist and botanist which now limits to either the Yangtze River of China or India.

2.2 Taxonomy of Rice

In the publication by Ministry of Environment and Forests Government of India (MOEF) (2011), the taxonomy and the botanical features of rice are described. The taxonomy classifications of rice in botanical field in order of kingdom, division, class, order, family, genus, and species are Plantae, Magnoliophyte, Liliopsida, Cyperales, Gramineae, *Oryza* and sativa. It is commonly referred as rice in English. In Malaysia, the grain is called "beras" and the plant is called "padi".

2.3 Botany of Rice

According to MOEF (2011), rice is an annual grass. It grows up to 1.8 metre (m), has round, hallow and jointed culms, and produce flat leaves and a terminal inflorescence. Each culm or tiller is also a shoot that includes root, stem and leaves. Rice is monocarpic plant, that is, flowers once, set seeds and die.

The root system of rice is divided into two major types which are crown roots and nodal roots. The crown roots are the ones that develop from nodes below the soil surface whereas the nodal roots develop from nodes above the soil surface. Rice root has the distinguished feature of dimorphism. Originally, they are thick and white with numerous root hairs on the entire surface. Then they become thinner, branched and brownish with hairs left only on the root apex. The root hairs are generally short lived and function as tubular extensions of the outermost layer of root. Only at later stage of plant growth, the main rooting system develops. At this time, the roots develop horizontally from the nodes of stem below ground level.

Stem of the rice plant consists of two parts which are underground and aerial parts. Aerial part of the stem is also called culm, which consists of several nodes spaced apart by internodes. The aerial part also has well-defined solid nodes and hollow internodes with thickness of about 6 to 8 millimetre (mm). Primary tillers usually emerge alternatively from the main stem, projecting in upward direction. Then, secondary tillers will emerge from the first node of the primary tiller. Ligules and a pair of auricles will grow at the leaf junction of the furthermost node. Also at the furthermost node, the panicle is formed and give rise to the spikelet.

The leaf arrangement of rice is alternate. The number of leaves borne on an axis is same as the number of nodes. The leaf can also be differentiated into two parts which are the leaf blade and leaf sheath. Leaf sheath is the elongated, cylindrical structure that wraps the culms, which also enclose the bud of potential tiller. The leaf blade is flat, elongated and is usually longer than the sheath. It has the major function of performing photosynthesis. Rice leaf may look like other grasses, but it can be distinguished by the presence of auricle and ligule.

The inflorescence of rice is the terminal panicle with single flowered spikelet. It is grown at the last internode of the culm. The rice spikelet consists of two short sterile lemma, a normal fertile lemma and palea. The floral organs are protected within the lemma and palea. When the floral organs mature, the lodicules in the flower will swell and spikelet will open to expose the mature floral parts.

The rice grain is a dry and one-seed fruit. Its pericarp is fused with the seed coat. The hull is the outer protective covering of the grain that consists of a lemma, a palea, an awn, a rachilla and two sterile lemmas. It accounts for 20% of the total seed weight. Other parts of the grain include the pericarp, seed coat, nucellus, embryo and endosperm. The endosperm consists of starch, protein and fat. The aleurone layer in the embryo stores food needed for germination. Different cultivars have different grain length which varies between 5 and 7 mm with round, bold or slender shape (MOEF, 2011). Figure 2.1 shows the morphology of a rice plant with four tillers.

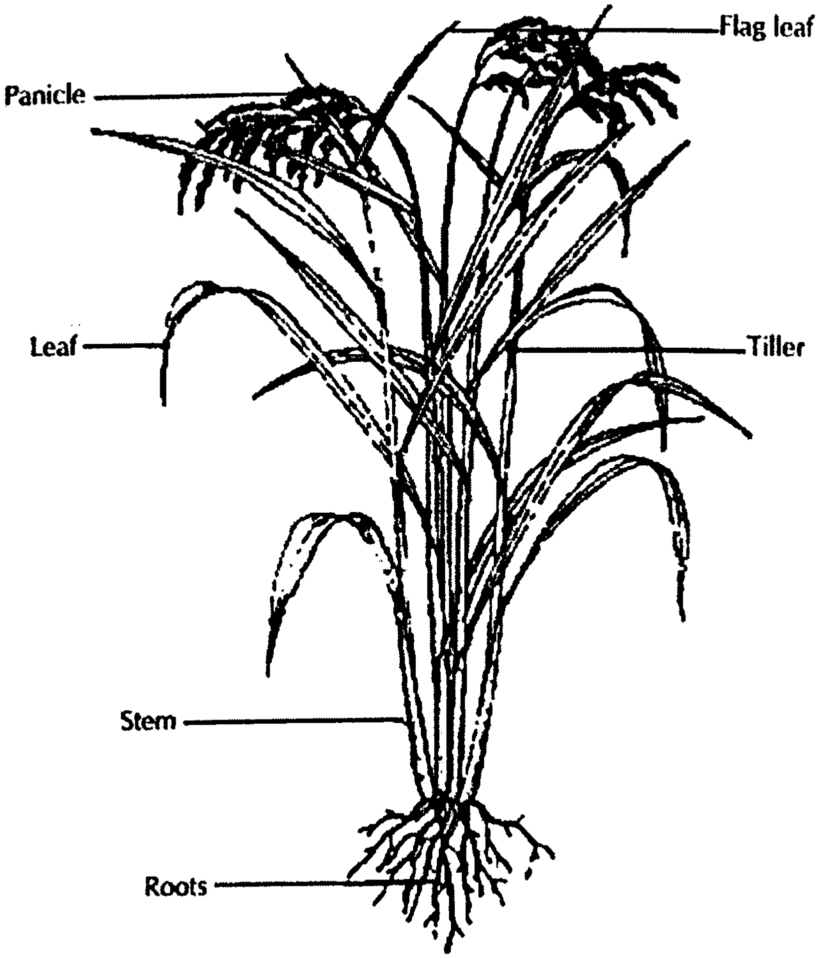

Figure 2.1 Morphology of a rice plant.
Source: Oikeh *et al.*, 2008

2.3.1 Flag Leaf

Flag leaf is the last mature leaf before flowering takes place in paddy. The length of flag leaf ranges between 100 to 300 mm whereas the width ranges between 10 to 25 mm (Torres and Pietragalla, 2012). According to Li *et al.* (1998), it is the major carbohydrate producer in paddy plant, whereby it provides more than 50% of the photosynthetic products mainly to the panicle.

The size and shape of flag leaf influence the generation of photosynthetic products and thus are directly responsible for the yield potential of paddy. It was found that the flag leaf area was positively correlated with the potential yield and number of spikelet per panicle of paddy (Yue *et al.*, 2006).

2.4 Growth Stages of Rice

The growth stages of rice plant is usually divided into three distinct and sequential phases. Yoshida (1981) stated the three phases are vegetative growth stage, reproductive growth stage and ripening growth stage. Figure 2.2 shows the growth phases of the rice plant.

According to MOEF (2011), the three phases are further subdivided into 10 stages. The Stage 0 is from germination to emergence. Stage 1 is called seedling. Stage 2 is tillering and Stage 3 is stem elongation. These first 4 stages make up the vegetative phase, the first phase of rice plant growth. Stage 4 is panicle initiation to booting. Stage 5 is heading or panicle exertion and stage 6 is flowering. Stages 4, 5, and 6 constitute the reproductive phase, the second phase of rice growth. Stage 7 is the milk grain stage. Stage 8 is the dough grain stage and stage 9 is the mature grain stage. Stages 7 through 9 correspond to the ripening phase, the last phase in the development of the rice plant.

Rice varieties can be categorized into short-duration varieties which mature in 105 to 120 days and the long duration varieties which mature in 150 days.

During the vegetative phase, the rice plants undergoes germination to emergence, seedling stage, tillering stage and stem elongation. During germination, the radicle and plumule will protrude through the hull. After two of three days of seeding, the first leaf breaks through the coleoptile. The seedling stage initiates soon after emergence and lasts till the first tiller appears. In the tillering stage, seminal roots and up to five leaves develop at the rate of one every three to four days. The tillering stage extends from the appearance of the first tiller until the maximum tiller number is reached. The stem elongation stage may begin before panicle initiation or occur during later part of tillering stage.

For the early-maturing varieties, the fourth internode of the stem, also the point below emergence of panicle, elongates only from 2 to 4 centimetre (cm) before panicle initiation becomes visible. In long-duration varieties, there will be a lag vegetative period when maximum tillering occurs before the panicle initiation.

As the panicle primordium initiates at the tip of the growing shoot, the reproductive phase starts. The panicle primordium will become visible to naked eye about 10 days after initiation. In short-duration varieties, the panicle becomes visible when a white feathery cone measuring about 1.0 to 1.5 mm long emerges from the main culm. This is also called the heading. Then it will appear in tillers in uneven pattern. During the development of panicle, the spikelet becomes recognizable. When the young panicle develops, booting occurs due to the bulging of the leaf sheath. Senescence of leaves and non-bearing tillers become noticeable at the plant base. For the Stage 6, also the flowering stage, the anthers protrude from the spikelet and fertilization starts taking place. The florets will open and the pollen from the protruded anthers will be shed on the pistil, thereby fertilizing the egg. Generally, the florets open in the morning. The flowering will occur a day after heading and takes about seven days for all spikelet in a panicle to open.

After the flowering stage, the ripening phase begins. Milky white liquid begins to fill the grain. Panicle will start to look green and bent. The senescence of the tillers will be progressing at the base. Moving to Stage 8, the milky liquid in the grain turns into soft dough and later hard dough. The spikelet turns yellow and senescence of tillers and leaves become obvious. In the last stage, each of the individual grain has matured, well developed and turns yellow and hard. Most of the leaves are dried and accumulated at the base of plant.

REFERENCES

Abd Allah, A. A. 2009. Genetic Studies on Leaf Rolling and Some Root Traits under Drought Conditions in Rice (*Oryza sativa* L.). *African Journal of Biotechnology* **8(22)**: 6241–6248

Ahmadikhah, A. and Marufinia, A. 2016. Effect of Reduced Plant Height on Drought Tolerance in Rice. *3 Biotech* **6(2)**: 221

Akinbile, C. O. 2010. Behavioural Pattern of Upland Rice Agronomic Parameters to Variable Water Supply in Nigeria. *Journal of Plant Breeding and Crop Science* **2(4)**: 73-80

Anjum, S. A., Xie, X., Wang, L., Saleem, M. F., Man, C. and Lei, W. 2011. Morphological, Physiological and Biochemical Responses of Plants to Drought Stress. *African Journal of Agricultural Research* **6(9)**: 2026–2032

AOSA. 2014. Rules for Testing Seeds. *Journal of Seed Technology* **16(3)**: 1-113

Arraudeau, M. A. 1995. Upland Rice: Challenges and Opportunities in a Less Favorable Ecosystem. *GeoJournal* **35(3)**: 325-328

Arraudeau, M. A. and Vergara, B. S. 1988. Major Insect Pests during Vegetative Phase. In Arraudeau, M. A. and Vergara, B. S. (Eds.). *A Farmer's Primer on Growing Upland Rice*. Los Baños: IRRI and IRAT

Asch, F., Dingkuhn, M., Sow, A. and Audebert, A. 2005. Drought-induced Changes in Rooting Patterns and Assimilate Partitioning between Root and Shoot in Upland Rice. *Field Crops Research* **93**: 223-226

Ashfaq, M., Haider, M. S., Khan, A. S. and Allah, S. U. 2012. Breeding Potential of the Basmati Rice Germplasm under Water Stress Condition. *African Journal of Biotechnology* **11(25)**: 6647–6657

Bates, L. S., Waldren, R.P. and Teare, I. D. 1973. Rapid Determination of Free Proline for Water Stress Studies. *Plant and Soil* **39**: 205-207

Biswas, A. K. and Choudhuri, M. A. 1984. Effect of Water Stress at Different Developmental Stages of Field-grown Rice. *Biologia Plantarum* **26(4)**: 263–266

Blum A. 2011. Drought Tolerance: Is It a Complex Trait? *Functional Plant Biology* **38(10)**: 753–757

Bonnet, M., Camares, O. and Veisseire, P. 2000. Effect of Zinc and Influence of *Acremonium lolii* on Growth Parameters, Chlorophyll a Fluorescence and Antioxidant Enzyme Activities of Ryegrass (*Lolium perenne* L. cv Apollo). *Journal of Experimental Botany* **51(346)**: 945-953

Boonjung, H. and Fukai, S. 1996. Effects of Soil Water Deficit at Different Growth Stages on Rice Growth and Yield under Upland Conditions. 2. Phenology, Biomass Production and Yield. *Field Crops Research* **48:** 47–55

Bouman, B. A. M. and Toung, T. P. 2001. Field Water Management to Save Water and Increase its Productivity in Irrigated Lowland Rice. *Agricultural Water Management* **49(1):** 11-30

Bunnag, S. and Pongthai, P. 2013. Selection of Rice (*Oryza sativa* L.) Cultivars Tolerant to Drought Stress at the Vegetative Stage under Field Conditions. *American Journal of Plant Sciences* **4(9)**: 1701–1708

Cabuslay, G. S., Ito, O. and Alejal, A. A. 2002. Physiological Evaluation of Responses of Rice (*Oryza sativa* L.) to Water Deficit. *Plant Science* **163(4)**: 815–827

Cassel, D. K. and Nielsen, D. R. 1986. Field Capacity and Available Water Capacity. In Klute, A. (Ed.). *Methods of Soil Analysis Part 1 Physical and Mineralogical Methods Second Edition*. Wisconsin: American Society of Agronomy, Inc.

Cerqueira, F, B., Erasmo, E. A. L., Silva, J. I. C., Nunes, T. V., Carvalho, G. P. and Silva, A. A. 2013. Competition between Drought-tolerant Upland Rice Cultivars and Weeds under Water Stress Condition. *Planta Daninha* **31(2)**: 291–30

Chang, T. T. and Vergara, B. S. 1975. Varietal Diversity and Morphoagronomic Characteristics of Upland Rice. In IRRI (Ed.). *Major Research in Upland Rice.* Los Baños: IRRI

Chang, T. T., De Datta, S. K. and Coffman, W. R. 1975. Breeding Methods for Upland Rice. In IRRI (Ed.). *Major Research in Upland Rice.* Los Baños: IRRI

Cha-um, S., Boriboonkaset, T., Pichakum, A. and Kirdmanee, C. 2009. Multivariate Physiological Indices for Salt Tolerance Classification in indica Rice (*Oryza sativa* L. spp. *indica*). *General and Applied Plant Physiology* **35(1–2)**: 75-87

Cha-um, S., Yooyongwech, S. and Supaibulwatana, K. 2010. Water Deficit Stress in the Reproductive Stage of Four indica Rice (*Oryza sativa L.*) Genotypes. *Pakistan Journal of Botany* **42(5)**: 3387–3398

Chen, C. W., Yang, Y. W., Lur, H. S., Tsai, Y. G. and Chang, M. C. 2005. A Novel Function of Abscisic Acid in the Regulation of Rice (*Oryza sativa* L.) Root Growth and Development. *Plant and Cell Physiology* **47(1)**: 1-13

Chesworth, W. (Ed.). 2008. *Encyclopedia of Soil Science.* Dordrecht: Springer

Chutia, J. and Borah, S. P. 2012. Water Stress Effects on Leaf Growth and Chlorophyll Content but not the Grain Yield in Traditional Rice (*Oryza sativa* Linn.) Genotypes of Assam, India: II. Protein and Proline Status in Seedlings under PEG Induced Water Stress. *American Journal of Plant Sciences* **3(7)**: 971-980

Clark, L. J., Price, A. H., Steele, K. A. and Whalley, W. R. 2008. Evidence from Near-Isogenic Lines that Root Penetration Increases with Root Diameter and Bending Stiffness in Rice. *Functional Plant Biology* **35(11)**: 1163-1171

Cogdell, R. J. 1978. Carotenoids in Photosynthesis. *Philosophical Transactions of the Royal Society B* **284(1002)**: 569-579

Cui, K. Peng, S., Ying, Y., Yu, S. and Xu, C. 2004. Molecular Dissection of the Relationships among Tiller Number, Plant Height and Heading Date in Rice. *Plant Production Science* **7(3)**: 309-318

Daie, J. 1996. Metabolic Adjustments, Assimilate partitioning and Alterations in Source-sink Relations in Drought-stressed Plants. In Zamski, E. and Schaffer, A. A. (Eds.). *Photoassimilate Distribution in Plants and Crops: Source-sink Relationships.* New York: Marcel Dekker

Davatgar, N., Neishabouri, M. R., Sepaskhah, A. R. and Soltani, A. 2009. Physiological and Morphological Responses of Rice (*Oryza sativa L.*) to Varying Water Stress Management Strategies. *International Journal of Plant Production* **3(4)**:19-32

Dey, M. M. and Upadhyaya, H. K. 1996. Yield Loss Due to Drought, Cold and Submergence Tolerance. In Evenson, R. E., Herdt, R. W., Hossain, M. (Eds.). *Rice Research in Asia: Progress and Priorities.* UK: International Rice Research Institute in Collaboration with CAB International

DOA. 2014. *Paddy Statistics of Malaysia.* Department of Agriculture Peninsular Malaysia.

Fahramand, M., Mahmoody, M., Keykha, A., Noori, M. and Rigi, K. 2014. Influence of Abiotic Stress on Proline, Photosynthetic Enzymes and Growth. *International Research Journal of Applied and Basic Sciences* **8(3)**: 257-265

Farooq, M. A., Wahid, N., Kobayashi, D., Fujita, and Basra, S. M. A. 2009. Plant Drought Stress: Effects, Mechanisms and Management. *Agronomy for Sustainable Development* **29(1)**: 185-212

Fukai, S. and Cooper, M. 1995. Development of Drought-resistant Cultivars Using Physio-morphological Traits in Rice. *Field Crops Research* **40**: 67–86.

Gana, A. S. 2011. Screening and Resistance of Traditional and Improved Cultivars of Rice to Drought Stress at Badeggi, Niger State, Nigeria. *Agriculture and Biology Journal of North America* **2(6)**: 1027–1031.

Garrity, D. P. and O'Toole, J. C. 1994. Screening Rice for Drought Resistance at the Reproductive Phase. *Field Crops Research* **39**: 99-110

Gee, G. W. and Bauder, J. W. 1986. Particle-size Analysis. In Klute, A. (Ed.). *Methods of Soil Analysis Part 1 Physical and Mineralogical Methods Second Edition.* Wisconsin: American Society of Agronomy, Inc.

Gomez, K. 1972. Measuring Plant Height and Tiller Number. In Gomez, K. (Ed.). *Techniques for Field Experiments with Rice.* Los Baños: IRRI

Gowda, V. R. P., Henry, A., Yamauchi, A., Shashidhar, H. E. and Serraj, R. 2011. Root Biology and Genetic Improvement for Drought Avoidance in Rice. *Field Crops Research* **122:** 1-3

Gupta, P. C. and O'Toole, J. C. 1986a. Insect Pest Management. In Gupta, P. C. and O'Toole, J. C. (Eds.). *Upland Rice: A Global Perspective.* Manila: IRRI

Gupta, P. C. and O'Toole, J. C. 1986b. Varietal Improvement. In Gupta, P. C. and O'Toole, J. C. (Eds.). *Upland Rice: A Global Perspective.* Manila: IRRI

Ha, P. T. T. 2014. Physiological Responses of Rice Seedlings under Drought Stress. *Journal of Science and Development* **12(5)**: 635–640

Harada, J. and Yamazaki K. 1993. Roots. In Matsuo, T. and Hoshikawa, K. (Eds.). *Science of the Rice Plant. Volume 1: Morphology.* Tokyo: Food and Agriculture Policy Research Centre

Hayat, S., Hayat, Q., Alyemeni, M. N., Wani, A. S., Pichtel, J. and Ahmad A. 2012. Role of Proline under Changing Environments: A Review. *Plant Signal Behaviour* **7(11)**: 1456-1466

Hoshikawa, K. (Ed.) 1989. *The Growing Rice Plant: An Anatomical Monograph.* Tokyo: Nobunkyo

Hsiao, T. C., O'Toole, J. C., Yambao, E. B. and Turner, N. C. 1984. Influence of Osmotic Adjustment on Leaf Rolling and Tissue Death in Rice (*Oryza sativa* L.). *Plant Physiology* **75(1)**:338-341

Huang, X., Qian, Q., Liu, Z., Sun, H., He, S., Luo, D., Xia, G., Chu, C., Li, J. and Fu, X. 2009. Natural Variation at the DEP1 Locus Enhances Grain Yield in Rice. *Nature Genetics* **41**: 494–497

IRRI. 1975. Characteristics of Plant Rice. In IRRI. (Ed.). *Major Research in Upland Rice.* Manila: IRRI.

IRRI. 1984. Upland Rice in Asia. In: An Overview of Upland Rice Research. Proceedings of the 1982 Bouaké, Ivory Coast Upland Rice Workshop. Los Baños, Philippines. 45-68

ISRIC. 2016. Acrisols. ISRIC

Jackson, M. L. 1956. Phosphorus Determinations for Soils. In Jackson, M. L. (Ed.). *Soil Chemical Analysis.* New Jersey: Prentice-Hall, Inc

Jaleel, C. A., Manivannan, P., Wahid, A., Farooq, M., Al-Juburi, H. J., Somasundaram, R. and Panneerselvam, R. 2009. Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition. *International Journal of Agriculture and Biology* **11**: 100–105.

Ji, K. X., Wang, Y. Y., Sun, W. N., Lou, Q. J., Mei,H. W., Shen, S. H. and Chen, H. 2012. Drought-responsive Mechanisms in Rice Genotypes with Contrasting Drought Tolerance during Reproductive Stage. *Journal of Plant Physiology* **169(4)**: 336–344

Johnson, D. E., Dingkuhn, M., Jones, M. P. and Mahamane, M. C. 1998. The Influence of Rice Plant Type on the Effect of Weed Competition on *Oryza sativa* and *Oryza glaberrima. Weed Research* **38(3)**: 207-216

Kadioglu, A. and Terzi, R. 2007. A Dehydration Avoidance Mechanism: Leaf Rolling. *Botanical Review* **73(4)**: 290–302

Kadioglu, A., Terzi, R., Saruhan, N. and Saglama, A. 2012. Current Advances in the Investigation of Leaf Rolling Caused by Biotic and Abiotic Stress Factors. *Plant Science* **182**: 42-48

Kaiser, W. M. 1987. Effect of Water Deficit on Photosynthetic Capacity. Plant *Physiologia Plantarum* **71(1)**: 142-149

Kato, Y., Abe, J., Kamoshita, A., and Yamagishi, J. 2006. Genotypic Variation in Root Growth Angle in Rice (*Oryza sativa* L.) and its Association with Deep Root Development in Upland Fields with Different Water Regimes. *Plant and Soil* **287(1)**:117–129

Kavar, T., Maras, M., Kidric, M., Sustar-Vozlic J. and Meglic V. 2007. Identification of Genes Involved in the Response of Leaves of *Phaseolus vulgaris* to Drought Stress. *Molecular Breeding* **21(2)**: 159–172

Kawata, S. and Soejima, M. 1974. On Superficial Root Formation in Rice Plants. *Japanese Journal of Crop Science* **43(3)**: 354-374

Khush, G. S. 2005. What It Will Take to Feed 5.0 Billion Rice Consumers in 2030. *Plant Mocelular Biology* **59**: 1-6

Kishor, P. B. K., Sangama, S., Amrutha, R. N., Laxmi, P. S., Naidu, K. R. and Rao, K. S. 2005. Regulation of Proline Biosynthesis Degradation, Uptake and Transport in Higher Plants: Its Implications in Plant Growth and Abiotic Stress Tolerance. *Current Science* **88(3)**: 424-438

Kulik, M. M. 1977. Seed Germinability Tests for Predicting Field Emergence of Rice Seeds Infected with *Helminthosporium oryzae* and *Trichoconis padwickii. Phytopathology* **67**:1303-1304

Kumar, S., Dwivedi, S. K., Singh, S. S., Bhatt, B. P., Mehta, P., Elanchezhian, R., Singh, V. P. and Singh, O. N. 2014. Morphophysiological Traits Associated with Reproductive Stage Drought Tolerance of Rice (*Oryza sativa L.*) Genotypes under Rain-fed Condition of Eastern Indo-Gangetic Plain. *Indian Journal of Plant Physiology* **19(2)**: 87–93

Lanceras, J. C., Pantuwan, G. P., Jongdee, B. and Toojinda, T. 2004. Quantitative Trait Loci Associated with Drought Tolerance at Reproductive Stage in Rice. *Plant Physiology* **135**: 384–399

Li, Z. K., Pinson, S. R., Stansel, J. W. and Paterson, A.H. 1998. Genetic Dissection of the Source-sink Relationship Affecting Fecundity and Yield in Rice (*Oryza sativa* L.). *Molecular Breeding* **4**:419-426

Lichtenthaler, H.K. 1987. Chlorophylls and Carotenoids: Pigments of Photosynthetic Biomembranes. *Methods in Enzymology* **148**: 350-380

Ligunjang, C. 2010. Satial Variability of Soil pH, Exhangeable Potassium, Calcium and Magnesium of a Selected Area at University Malaysia Sabah Campus in Sandakan. Bachelor of Agricultural Science Dissertation. Universiti Malaysia Sabah.

Ling, Z. M., Li, Z. C., Yu, R. and Mu, P. 2002. Agronomic Root Characters of Upland Rice and Paddy Rice (*Oryza sativa* L.) *Journal of China Agricultural University* **7(3)**:7-11

Liu, J. X., Liao, D. Q., Oane, R., Estenor, L., Yang, X. E., Li, Z. C. and Bennet, J. 2006. Genetic Variation in the Sensitivity of Anther Dehiscence to Drought Stress in Rice. *Field Crops Research* **97**: 87-100

Lo, S. F., Yang, S. Y., Chen, K. T., Hsing, Y. I., Zeevaart, J. A., Chen, L. J. and Yu, S. M. 2008. A Novel Class of Gibberellin 2-oxidases Control Semidwarfism, Tillering, and Root Development in Rice. *Plant Cell* **20(10)**: 2603–2618

Lorenz, G. and Hardke, J. 2013. Insect Management in Rice. In Hardke, J. (Ed.). *Arkansas Rice Production Handbook.* Arkansas: University of Arkansas Division of Agriculture

Ludlow M. M., Muchow R. C. 1990. A Critical Evaluation of Traits for Improving Crop Yields in Water-limited Environments. *Advances in Agronomy* **43**: 107-153

Lum, M. S., Hanafi, M. M., Rafii, Y. M. and Akmar, A. S. N. 2014. Effect of Drought Stress on Growth, Proline and Antioxidant Enzyme Activities of Upland Rice. *Journal of Animal and Plant Science* **24(5)**: 1487-1493

Maisura, Chozin, M. A., Lubis, I., Junaedinand, A. and Ehara, H. 2014. Some Physiological Character Responses of Rice under Drought Conditions in a Paddy System. *Journal of the International Society for Southeast Asian Agricultural Sciences* **20(1)**: 104–114

Malaysia. 1998. *The Third Agricultural Policy (1998 – 2010).* Kuala Lumpur: Ministry of Agriculture

Manikavelu, A., Nadarajan, N., Ganesh, S. K., Gnanamalar, R. P. and Chandra Babu R. 2006. Drought Tolerance in Rice: Morphological and Molecular Genetic Consideration. *Plant Growth Regulation* **50(2/3)**: 121–138

Marschner, H. 1998. Role of Root Growth, Arbuscular Mycorrhiza, and Root Exudates for the Efficiency in Nutrient Acquisition. *Field Crop Research* **56**: 203-207

Matsui, T. and Singh, B. B. 2003. Root Characteristics in Cowpea Related to Drought Tolerance at the Seedling Stage. *Experimental Agriculture* **39(1)**:29 – 38

McGeehan, S. L. and Naylor, D. V. 1988. Automated Instrumental Analysis of Carbon and Nitrogen in Plant and Soil Samples. *Communications in Soil Science and Plant Analysis* **19(4)**: 493-505

Medrano, H., Escalona J. M., Bota, J., Gulías, J. and Flexas, J. 2002. Regulation of Photosynthesis of C3 Plants in Response to Progressive Drought: Stomatal Conductance as a Reference Parameter. *Annals of Botany* **89**: 895-905

MOEF. 2011. *Biology of Oryza sativa L. (Rice).* Department of Biotechnology Ministry of Science & Technology Government of India.

Moldenhauer, K., Wilson, C. E., Counce, J.P. and Hardke, J. 2013. Rice Growth and Development. In Hardke, J. T. (Ed.). *Arkansas Rice Production Handbook.* Arkansas: University of Arkansas Division of Agriculture

Morgan P. W. 1990. Effects of Abiotic Stresses on Plant Hormone Systems. In Alscher, R. G. and Cumming, J. R. (Eds.). *Stress Responses in Plants: Adaptation and Acclimation Mechanisms* New York: Wiley-Liss

Morita, S. and Yamazaki K. 1993. Root System. In Matsuo, T. and Hoshikawa, K. (Eds.). *Science of the Rice Plant.* Tokyo: Food and Agriculture Policy Research Centre

Mostajeran, A. and Rahimi-Eichi, V. 2009. Effects of Drought Stress on Growth and Yield of Rice (*Oryza sativa* L.) Cultivars and Accumulation of Proline and Soluble Sugars in Sheath and Blades of Their Different Ages Leaves. *American-Eurasian Journal of Agricultural and Environmental Science* **5(2)**: 264-272

Moulia, B. 1994. Biomechanics of Leaf Rolling. *Biomimetics* **2**: 267–281

Mullan, D. and Pietragalla J. 2012. Leaf Relative Water Content. In Saint Pierre, C., Pask, A. J. D., Pietregalla, J., Mullan, D. M., Reynolds, M. P. and Tellez Arce, V. (Eds.). *Canopy Temperature, Stomatal Conductance and Water Relation Traits: Leaf Water Potential.* Mexico: Centro Internacional de Mejoramiento de Maíz y Trigo

Nguyen, H. T., Babu, R. C. and Blum, A. 1997. Breeding for Drought Resistance in Rice: Physiological and Molecular Genetics Considerations. *Crop Science* **37(5)**: 1426-1434

O'Toole, J. C. 1982. Adaptation of Rice to Drought-prone Environments. In IRRI. (Ed.). *Drought Resistance in Crops with Emphasis on Rice*. Los Banos: IRRI

O'Toole, J. C. and De Datta, S. K. 1986. Drought Resistance in Rainfed Lowland Rice. In Banta, S. and IRRI. (Eds.). *Progress in Rainfed Lowland Rice*. Makati City: IRRI

O'Toole, J. C., and Cruz, R. 1979. Leaf Rolling and Transpiration. *Plant Science Letters* **16(1)**: 111-114

Oikeh, S. O., Nwilene, F. E., Agunbiade, T. A., Oladimeji, O., Ajayi, O., Semon, M., Tsunematsu, H. and Samejima, H. 2008. Fertilizers Recommendation. In Oikeh, S. O., Nwilene, F. E., Agunbiade, T. A., Oladimeji, O., Ajayi, O., Semon, M., Tsunematsu, H. and Samejima, H. (Eds.). *Growing Upland Rice: A Production Handbook.* Benin: WARDA

Oka, H. I. and Morishima, H. 1982. Potentiality of Wild Progenitors to Evolve the *indica* and *japonica* Types of Rice Cultivars. Phylogenetic Differentiation of Cultivated Rice, XXIII. *Euphytica* **31**: 41-50.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. 1993. (Ed.) *Laboratory Methods of Soil and Plant Analysis: A Working Manual.* Nairobi: TSBF

O'Toole, J. C. and Chang, T. T. 1979. Drought Resistance in Cereals-rice: A Case Study. In Mussell, H. and Staples, R. C. (Eds.). *Physiology of Crop Plants.* New York: Wiley

Padmavathi, C., Katti, G., Padmakumari, A. P., Voleti, S. R. and SubbaRao, L. V. 2013. The Effect of Leaffolder *Cnaphalocrocis medinalis* (Guenee) [Lepidoptera: Pyralidae] Injury on the Plant Physiology and Yield Loss in Rice. *Journal of Applied Entomology* **137(4)**: 249–256

Panagos, P., Jones, A., Bosco, C. and Senthil Kumar, P. S. 2011. European Digital Archive on Soil Maps (EuDASM): Preserving Important Soil Data for Public Free Access. *International Journal of Digital Earth* **4(5)**: 434-443

Pandey, S. and Bhandari, H., 2009. Drought, Coping Mechanisms and Poverty: Insights from Rainfed Rice Farming in Asia. International Fund for Agricultural Development (IFAD)

Pandey, V. and Shukla, A. 2015. Acclimation and Tolerance Strategies of Rice under Drought Stress. *Rice Science* **22(4)**: 147-161

Pantuwan, G., Fukai, M., Cooper, S., Rajatasereekul, S. and O'Toole, J. C. 2002. Yield Response of Rice (*Oryza sativa* L.) Genotypes to Drought under Rainfed Lowlands. 2. Selection of Drought Resistant Genotypes. *Field Crop Research* **73(2-3)**: 169-180

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

Passioura, J. B. 2007. The Drought Environment: Physical, Biological and Agricultural Perspectives. *Journal of Experimental Botany* **58(2)**: 113-117

Pathak, M. D. 1991. Agronomic Practices for Different Cultural Types of Rice. In Pathak, M. D. (Ed.). *Rice Production in Uttar Pradesh: Progress and Suggestions for Improvement.* New Delhi: Wiley Eastern Limited

Peace Corps. 1982. Seed Selection and Preparation. In: Rice Production: A Training Manual and Field Guide to Small-Farm Irrigated Rice Production. Appropriate Technologies for Development. Reprint No. R-40. Peace Corps Information Collection and Exchange

Peter, J., Nathan, M. and Laboski, C. 2012. pH and Lime Requirement. In Agricultural Experiment Stations of Illinois (Ed.). *Recommended Chemical Soil Test Procedures for the North Central Region.* Columbia: Missouri Agricultural Experiment Station

Pirdashti, H., Sarvestani, Z. T. and Bahmanyar, M, A. 2009. Comparison of Physiological Responses among Four Contrast Rice Cultivars under Drought Stress Conditions. *Proceedings of World Academy of Science, Engineering and Technology* **49**: 52–53.

Pireivatloum, J., Qasimov, N. and Maralian, H. 2010. Effect of Soil Water Stress on Yield and Proline Content of Four Wheat Lines. *African Journal of Biotechnology* **9**: 36-40

Price, A. H., Young, E. M. and Tomos, A. D. 1997. Trait Loci Associated with Stomatal Conductance, Leaf Rolling and Heading Date Mapped in Upland Rice (*Oryza sativa*). *New Phytologist* **137**: 83–91

Quarrie, S. A. and Jones, H. G. 1977. Effects of Abscisic Acid and Water Stress on Development and Morphology of Wheat. *Journal of Experimental Botany* **28(1)**: 192-203

Rahman, M. T., Islam, M. T. and Islam, M. O. 2002. Effect of Water Stress at Different Growth Stages on Yield and Yield Contributing Characters of Transplanted Aman Rice. *Pakistan Journal of Biological Sciences* **5(2)**: 169-172

Ross, D. S. and Ketterings, K. Q. 2011. Recommended Methods for Determining Soil Cation Exchange Capacity. In University of Delaware (Ed.). *Recommended Soil Testing Procedures for the Northeastern United States.* Delaware: Cooperative Extension, University of Delaware

Roy, R. N. and Misra, R. V. 2002. Economic and Environmental Impact of Improved Nitrogen Management in Asia Rice-farming Systems. In: *Proceedings of the 20th Session the International Rice Commission.* 23 – 26 July 2002. Bangkok

Saito, K., Linquist, B., Atlin, G. N., Phanthaboon, K., Shiraiwa, T. and Horie, T. 2005. Response of Traditional and Improved Upland Rice Cultivars to N and P in Northern Laos. *Field Crops Research* **96(2-3)**: 216-223

Salunkhe, A. S., Poornima, R., Prince, K. S., Kanagaraj, P., Sheeba, J. A., Amudha, K., Suji, K. K., Senthil, A. and Babu, R. C. 2011. Fine Mapping QTL for Drought Resistance Traits in Rice (*Oryza sativa* L.) Using Bulk Segregant Analysis. *Molelucar Biotechnology* **49(1)**: 90–95

Samson, B. K., Hasan, H. and Wade, L. J. 2002. Penetration of Hardpans by Rice Lines in the Rainfed Lowlands. *Field Crops Research* **76(2/3)**: 175–188

Sarvestani, Z. T., Pirdashti, H., Sanavy, S. A. M. M. and Balouchi H. 2008. Study of Water Stress Effects in Different Growth Stages on Yield and Yield Components of Different Rice (*Oryza sativa* L.) Cultivars. *Pakistan Journal of Biological Sciences* **11(10)**: 1310-1309

SAS Institute Inc. 2002. SAS Version 9.4. SAS Institute. North Carolina (USA)

Shabala, S. N., Shabala, S. I., Martynenko, A. I., Babourina, O. and Newman, I. A. 1998. Salinity Effect on Bioelectric Activity, Growth, Na^+ Accumulation and Chlorophyll Fluorescence of Maize Leaves: A Comparative Survey and Prospects for Screening. *Australian Journal of Plant Physiology* **25**: 609-616

Sharma, S. S. and Dietz, K.J. 2006. The Significance of Amino Acids and Amino-acid Derived Molecules in Plant Responses and Adaptation to Heavy Metal Stress. *Journal of Experimental Botany* **57(4)**: 711-726

Sharp, R. E., Wu, Y., Voetberg, G. S., Saab, I. N. and LeNoble, M. E. 1994. Confirmation that Abscisic Acid Accumulation is required for Maize Primary Root Elongation at Low Water Potentials. *Journal of Experimental Botany* **45**: 1743-1751

Shashidhar, H. E., Vimarsh Gowda, H. S., Raveendra, G. M., Kundur, P. J., Kumar, G.N., Suprabha, N., Upadhya, P. and Sonam, R. 2012. PVC Tubes to Characterize Roots and Shoots to Complement Field Plant Productivity Studies. In Shashidhar, H. E., Henry, A. and Hardy, B. (Eds.). *Methodologies for Root Drought Studies in Rice.* Los Baños: IRRI

Sheela, K. R. and Alexallder, V. T. 1995. Physiological Response of Rice Varieties as Influenced by Soil Moisture and Seed Hardening. *Indian Journal of Plant Physiology* **38(3)**: *269-271*

Sikuku, P. A., Netondo, G. W., Onyango, J. C. and Musyimi, D. M. 2010. Chlorophyll Fluorescence, Protein and Chlorophyll Content of Three NERICA Rainfed Rice Varieties under Varying Irrigation Regime. *Agricultural and Biological Science* **5(2)**: 19-25

Singh, A., Sengar, K., Sengar, R. S. 2013. Gene Regulation and Biotechnology of Drought Tolerance in Rice. *International Journal of Biotechnology and Bioengineering Research* **4(6)**: 547–552

Singh, D. K., Sale, P. W. G., Pallaghy, C. K. and Singh, V. 2000. Role of Proline and Leaf Expansion Rate in the Recovery of Stressed White Clover Leaves with Increased Phosphorus Concentration. *New Phytologist* **146(2)**: 261-269

Sokoto, M. B. and Muhammad, A. 2014. Response of Rice Varieties to Water Stress in Sokoto, Sudan Savannah, Nigeria. *The Journal of Bioscience and Medicine* **2(1)**: 68–74

Spollen, W. G. and Sharp, R. E. 1991. Spatial Distribution of Turgor and Root Growth at Low Water Potentials. *Plant Physiology* **96(2)**:438-443

Subashri, M., Robin, S., Vinod, K. K., Rajeswari, S., Mohanasundaram, K. and Raveendran, T. S. 2009. Trait Identification and QTL Validation for Reproductive Stage Drought Resistance in Rice Using Selective Genotyping of Near Flowering RILs. *Euphytica* **166(2)**: 291–305

Taiz, L and Zeiger, E. (Eds.). 2006. *Plant Physiology*. Fourth Edition. Sunderland: Sinauer Associates

Taylor, I. B. 1991 Genetics of ABA Synthesis In Davies W. J. and Jones H, G. (Eds.). *Abscisic acid: Physiology and Biochemistry* UK: Bios Scientific Publishers Ltd.

Torres, A. and Pietragalla J. 2012. Crop Morphological Traits. In Pask, A., Pietragalla, J., Mullan, D. and Reynolds, M. (Eds.). *Physiological Breeding: A Field Guide to Wheat Phenotyping.* Mexico: CIMMYT

Trewavas, A. J. and Jones, H. G. 1991. An Assessment on the Role of ABA in Plant Development. In Davies, W. J. and Jones, H. G. (Eds.). *Abscisic Acid: Physiology and Biochemistry.* Oxford: Bios Scientific Publishers

Tripathy, J. N., Zhang, J. X., Robin, S., Nguyen, T. T. and Nguyen, H. T. 2000. QTLs for Cell-membrane Stability Mapped inRice (*Oryza sativa* L.) under Drought Stress. *Theoretical and Applied Genetics* **100(8)**: 1197–1202

Turner, N. C., O'Toole, J. C., Cruz, R. T., Namuco, O. S. and Ahmad, S. 1986. Responses of Seven Diverse Rice Cultivars to Water Deficits: I. Stress Development, Canopy Temperature, Leaf Rolling and Growth. *Field Crops Research* **13**: 257–271

Turner, N. C., Wright, G. C. and Siddique, K. H. M. 2001. Adaptation of Grain Legumes (Pulses) to Water-limited Environments. *Advances in Agronomy* **71**: 123–231

Vajrabhaya, M., Kumpun, W. and Chadchawan, S. 2001. The Solute Accumulation: The Mechanism for Drought Tolerance in RD23 rice (*Oryza sativa* L.) lines. *Science Asia* **27**: 93-97

Verbruggen, N. and Hermans, C. 2008. Proline Accumulation in Plants: A Review. *Amino Acids* **35(4)**: 753-759

Verma, V., Foullces, M. J., Worland, A. J., Bradley, S. R., Caligar, P. D. S. and Snape, J. W. 2004. Mapping Quantitative Trait Loci for Flag Leaf Senescence as a Yield Determinant in Winter Wheat under Optimal and Drought-stressed Environments. *Euphytica* **135(3)**: 255-263

Wang, H. and Yamauchi, A. 2006. Growth and Function of Roots under Abiotic Stress in Soil. In Huang B. R. (Ed.). *Plant-Environment Interactions. 3rd Edition*. New York: CRC Press

Wang, H., Bouman, B. A. M., Zhao, D., Wang, C. and Moya, P. F. 2002. Aerobic Rice in Northern China: Opportunites and Challenges. In Bouman, B. A. M., Hengsdijk, H., Hardy, B., Bindraban, P. S., Tuong, T. P. and Ladha, J. K. (Eds.). *Water-wise Rice Production.* Phillipines: IRRI

Wilkinson, S. and Davies, W. J. 2010. Drought, Ozone, ABA and Ethylene: New Insights from Cell to Plant to Community. *Plant, Cell and Environment* **33(4)**:510-25

Wopereis, M. S. C., Kropff, M. J., Maligaya, A. R. and Tuong, T. P. 1996. Drought-stress Responses of Two Lowland Rice Cultivars to Soil Water Status. *Field Crops Research* **46**: 21-39

Yambao, E. B., Ingram, K. T. and Real, J. G. 1992. Root Xylem Influence on the Water Relations and Drought Resistance of Rice. *Journal of Experimental Botany* **43(7)**: 925-932

Yoshida, S. (Ed.).1981. *Fundamentals of Rice Crop Science.* Los Banos: IRRI

Yoshida, S. and Hasagewa, S. 1982. The Rice Root System: Its Development and Function. In IRRI (Ed.). *Drought Resistance in Crops, with Emphasis on Rice.* Los Banos: IRRI

Yoshida, S., Bhattacharjee, D. P. and Cabuslay, G.S. 1982. Relationship between Plant Height and Root Growth. *Soil Science and Plant Nutrition* **28**: 473-482

Yue, B., Xue, W. Y., Luo, L. J. and Xing, Y. Z. 2006. QTL Analysis for Flag Leaf Characteristics and Their Relationships with Yield and Yield Traits in Rice. *Acta Genetica Sinica* **33**:824-832

Zhang, J., Zheng, H.G., Aarti, A., Pantuwan, G., Nguyen, T. T. and Tripathy, J. N. 2001. Locating Genomic Regions Associated with Components of Drought Resistance in Rice: Comparative Mapping Within and Across Species. *Theoretical and Applied Genetics* **103**: 19-29

Zhang, Q. 2007. Strategies for Developing Green Super Rice. In: *Proceedings of the National Academy of Sciences of the United States of America.* 24 August 2007. Washington, United Stated of America. 16402–16409

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

Zubarer, M. A., Chowdhury, A. K. M. M. B., Islam, M. Z., Ahmed, T. and Hasan, M. A. 2007. Effects of Water Stress on Growth and Yield Attributes of Aman Rice Genotypes. *International Journal of Sustainable Crop Production* **2(6)**: 25-30