

Effects of variety on yield and water productivity of fadama-grown rice (*Oryza sativa* L.) in Akure, southwestern Nigeria.

Abstract

Drought is the most important factor limiting rice productivity under rainfed system of the humid tropics. Field experiments were conducted to determine the effects of soil water management strategies (growth on residual soil moisture at the vegetative stage supplemented with irrigation at the reproductive stage and growth under full irrigation throughout) on water use, yield and yield components of four varieties of rice grown in the dry season in an inland valley swamp (fadama). The four varieties selected were two upland (Ekpoma local and upland Nerica 4) and two lowland (lowland Nerica 1 and 2). The first planting (December, 2010) adequacy of soil moisture from planting to date of first flowering was assumed, thereafter irrigation was imposed during reproductive growth. In the second sowing (January, 2011), rice plants were drip-irrigated from planting to seed harvest. The results indicated that differences between the December and January sowing dates were found significant for most of the traits measured (root and shoot weight, leaf area, plant height, number of tillers, panicle and seed weight, 100 seed weight and harvest index). Total seed yields and harvest indices (3.19 t ha^{-1} : 10.1) was higher in January over December (1.24 t ha^{-1} : 6.3) sowing in addition to higher water use efficiencies (0.053 and $0.031 \text{ t ha}^{-1} \text{ mm}^{-1}$). The seed yield reduction was associated with reductions in plant height (103.4 : 76.8 cm), leaf area (51.9 : 76.1 m^2) and shoot weight (103.7 : 76.8 g) across all tested lines. Seasonal soil moisture storage ranged from 186 to 223 mm for the respective first (December) and second (January) sowing dates. The two best lines (Upland Ekpoma and Nerica 4), had similar yield performance when grown under irrigation from planting to maturity (harvest) but differed significantly in their trait combinations. Over other varieties, upland Ekpoma and Nerica 4 exhibited superior ability to produce tillers, panicle and seed weights in both first and second sowing dates. Functional relationships between some weather variables and growth and yield characteristics of rice which gave high regression coefficients (R^2) showed that, the differences in shoot biomass and seed yield production between the sowing dates be explained by a combination of weather parameters. The evaluated varietal yield potential and related traits measured under variable soil moisture regimes were discussed in relation to genotypic adaptation (drought tolerance) among the tested rice varieties. It is concluded that, in a cultivar, higher yield potential may be related to ability to tolerate multiple and concurrent abiotic stresses of soil and air moisture deficit and temperature stresses.

Keywords: Inland flood plain, rice, water management, drought, heat, stress, adaptation.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple cereal grown worldwide especially in rainfed and irrigated cropping systems. Rice is one of the most common of all domesticated cereals, a tropical C_3 species, carries an odd behaviour of tolerance and susceptibility to abiotic stresses as compared to other field crops (Tuong et al., 1999). Rice thrives well in water logged soil and can

42 tolerate submergence at levels that would kill other crops, also is moderately tolerant of salinity
 43 and soil acidity, but highly sensitive to drought and cold (Narciso et al., 2000). In the lowland
 44 ecosystem, rice is subject to intermittent submergence (water depth of 0.5 to 1m that cover the
 45 foliage), to salinity stress in coastal regions and drought in upland conditions. The rainfed areas
 46 occupy about 30% of the total world rice growing areas where high yielding semi-dwarf rice
 47 varieties are not widely grown because of their poor adaptability to the more stressful rainfed
 48 conditions (Liu et al., 2005). Among the abiotic stresses in the rainfed systems, drought is the
 49 most important factor limiting rice productivity (Lafitte *et al.*, 2007; Ali *et al.*, 2008; Venuprasad
 50 *et al.*, 2008).

51 Tuong and Bauman (2003) presented a review of water productivity in rice and survey the
 52 irrigation and associated technologies available given a water limited future. The author
 53 concluded that periodic surface irrigation or flush irrigation methods are viable water
 54 management strategies for rice production. Water limited condition ~~(also referred to as drought)~~,
 55 affects 23 million hectares of rice yearly (Pandey et al., 2007) is a condition related to
 56 insufficient soil moisture available to support average crop production. Rice is particularly
 57 sensitive to drought stress and even mild drought stress can result in significant yield reduction
 58 in rice (O'Toole, 1982; Centritto *et al.*, 2009). Drought stress particularly during flowering stage
 59 can result in severe yield losses. The physiological processes during the sensitive flowering
 60 stage, negatively affecting spikelet fertility under water stress anther dehiscence and pollen
 61 germination (Ekanayake et al., 1990; Liu et al., 2005) were similar to high-temperature stress
 62 (Yoshida, 1981; Jagadish et al., 2010). Additionally, panicle exertion (O'Toole and Namuco,
 63 1983), and peduncle length (He et al., 2009) may be partly responsible for increased sterility
 64 under water stress. Genotypic attributes such as stature ~~(plant height and vigour)~~, tillering habits,
 65 root size, root morphology and density and other physiological attributes such as stomatal

closure and osmotic adjustment had been implicated as possible mechanisms for drought tolerance (Cutler et al., 1980; Liu et al., 2005).

The rice growing agroecologies are characterized by maximum day-time temperatures either close to or higher than the critical threshold ranging between 33°C (Nakagawa et al., 2002) and 35°C (Yoshida, 1981). High-temperature stress (~~temperatures beyond a critical threshold~~) can cause irreversible damage to plant growth and development (Wahid et al., 2007). Temperatures greater than 35°C at anthesis and lasting for more than 1 h can lead to high sterility in rice (Jagadish et al., 2007). A high-temperature stress-induced increase in spikelet sterility is attributable to abnormal anther dehiscence (Matsui and Omasa, 2002), impaired pollination (Matsui et al., 2005), and pollen germination (Jagadish et al., 2010). Moreover, high temperature of 39°C given a day before flowering resulted in poor anther dehiscence during subsequent anthesis (Matsui and Omasa, 2002). High temperatures stress given a day prior to anthesis affected the normal functioning of the pollen sac (~~anther~~) dehiscence and pollen viability (Matsui and Omasa, 2002). The reproductive stage in rice is effected irreversibly by high temperatures (Prasad et al., 2006) and soil moisture deficit stress than the vegetative stage. Water deficit during reproductive stage significantly reduces pollen viability, spikelet fertility (Praba et al., 2009) and grain yield (Boonjung and Fukai, 1996). The response of plants to water and temperature stresses depends on the duration and severity of the stress (Araus et al., 2002; Bartels and Souer, 2004) and the developmental stage (Zhu et al., 2005).

In future climates, rice could more subjected to simultaneous high temperature and water stress during sensitive developmental stages such as heading (~~anthesis~~) and seed filling. As the global climate changes (~~particularly as the warming temperature~~) continue, water shortage and drought have become an increasingly serious constraint limiting rice production worldwide (Wassmann et al., 2009). Hence, overcoming the effects of high temperature and water stress on rice production is essential in the attainment of food security now and in the future. Rice varieties are

different among regions and locality, and their response to ecological variations is different. The high yielding varieties of rice that had been developed will respond differently at different locations and ecosystem (agroecologies). There is need to investigate varietal suitability of rice especially the newly improved lines to the soil and weather condition in rice growing agroecologies of Nigeria.

In sub-Saharan Africa, inland wetlands constitutes about 135 million ha of land (IWMI, 2002). Extensive land areas in Nigeria are characterized by shallow water tables fed by streams and river courses (~~inland flood plains~~) and hence seasonally flooded. The inland wetlands (~~inland valley swamps/floodplains~~) are characterized by seasonal flooding at the peak of the rainy season, high residual moisture regimes in the dry season and variable but shallow ground water table depths. The agricultural potentials of tropical inland valley swamps or flood plains (Fadama ecosystem) can be harnessed via the effective management of its soil and water resources. Field experiments were conducted in order to examine pattern of water use, growth and yield of four varieties of rice grown in the dry season in an inland flood plain (fadama) under irrigation management strategies. The aim was to evaluate varietal yield potential and related traits under variable soil moisture regimes, and to examine the value of the measured traits to yield potentials and genotypic adaptation (~~drought tolerance~~) among the tested rice varieties.

MATERIALS AND METHODS.

Description of Study Area.

The study was conducted at the Teaching and Research Farm of the Federal University of Technology, Akure, a humid rainforest zone of southwest Nigeria (Lat. 7° 14' N and Long. 5° 08' E) and at 35 meters above sea level. The mean annual rainfall of between 1300-1600 mm and with an average temperature of 30°C. The relative humidity ranges between 85% during the rainy season and less than 60% during the dry season.

Two experiments were carried out between December, 2010 and May, 2011, to determine the effects of soil water management strategies (growth on residual soil moisture at the vegetative stage supplemented with irrigation at the reproductive stage and growth under full irrigation throughout) on water use, yield and yield components of four varieties of rice grown in the dry season in an inland valley swamp (fadama). The varieties evaluated are (i) Ekpoma local, (ii) Upland Nerica, (iii) Lowland Nerica 1 and (iv) Lowland Nerica 2. Rice seeds were planted on soil water reserve until peak vegetative growth (date of first flowering) after which irrigation was imposed during reproductive growth (flowering to crop maturity), and between January and May 2010). Seeds of four varieties of rice consisting of two upland (Ekpoma local and upland Nerica 4) and two lowland (Nerica 1 and 2) were obtained from the African Rice Centre, Ibadan and Edo State Agricultural Development project, Benin City. Rice seeds were sown on the field at 90 by 20 cm spacing along the row and at three replications per treatment. The experimental site consisted of two blocks each of which measures 13.50 x 90m. The land was manually cleared, packed, and Force-Up herbicide was applied at the rate of 3 litres per hectare to further prevent weed competition on the plots.

At maturity, six uniform plants of 0.3 m² in each plot were measured for plant height and sampled by cutting the plants from the bottom (right above the soil surface). The plants sampled from each plot were put into a paper bag and were then oven-dried at 75 °C for 3 days. The dried samples were then measured for total grain yield and its components, including biomass, 100-seed weight and panicle and spikelet weights.

Plant Measurements

Data were collected on root and shoot biomass, leaf area development, flowering and fruiting characters and grain yield of rice. Photographs of various operations were also taken on the field. Data were collected on pattern of soil moisture storage and depletion, and agronomic parameters of root and shoot biomass, leaf area and fruit yield characters of rice. Agronomic characters of root and shoot biomass, leaf area, seed yield and yield components were monitored from ten

143 plants per row. Root and shoot biomass were oven-dried at 80 °C for 48 h and dry weights were
144 recorded.

145 **Soil physical and chemical properties.**

146 Soil moisture was estimated by gravimetric method (oven-dried moist soil samples at 105 °C for
147 24 ~~hours~~). Core samples were taken at surface soil (10 cm ^{depth}) while bulk density that were
148 determined for the samples were employed in the conversion of gravimetric soil moisture
149 content to volumetric (cm³:cm⁻³). From the experimental field, ten points were sampled weekly
150 starting from planting to crop physiological maturity. Soil moisture depletion (SWD) were
151 obtained from the differences in soil moisture contents measured at the beginning and at the end
152 of weekly cycle.

153 Accumulated heat units (thermal time) was calculated from temperature coefficient for
154 individual crops. Thermal time (TT°Cd) for the phenological phases were calculated from the
155 daily maximum (T_{max}) and minimum (T_{min}) temperatures measured at the Meteorological
156 Observatory of the Department of Meteorology, FUT, Akure. Average daily temperature was
157 used to calculate thermal time (TT) for each growth phase. Cardinal temperatures (Nakagawa et
158 al., 2002; Jagadish et al., 2010), namely base temperature (T_b 8 °C), optimum temperature (T_{opt}
159 32 °C), and maximum temperature (T_{max} 42 °C), were assumed in the calculation of heat unit
160 accumulation measured as growing degree days (GDD) using equation of McMaster and
161 Wilhelm (1997).

$$162 \quad \quad \quad (T_{\max} + T_{\min})$$

$$163 \quad \text{GDD} \quad = \quad \frac{\quad}{2} - T_{\text{base}} \quad (1)$$

$$164 \quad \quad \quad 2$$

$$165 \quad \text{Thermal Time} = \frac{(T_{\max_{i-x}} - T_o)}{2 - T_b}$$

$$166 \quad \quad \quad (2)$$

167 T_{max} is the maximum temperature, T_o is optimum temperature and T_b is the base temperature,
 168 $1-x$ represents the time interval during which measurements were made (day one to the last day).
 169 Thermal time requirements ($TT^{\circ}Cd$) for the different growth phases can also be obtained from
 170 the sum of the calculated growing degree days summed over the growing season length (days).
 171 Weather variables at the site of experiment during crop growth cycle (soil and air temperatures,
 172 vapour pressure deficit (vPd), solar radiation, wind speed were monitored from Meteorological
 173 observatory, 500 meters from site of experiment.

174 **Irrigation strategies**

175 In the first experiment (December, 2010), adequacy of soil moisture from planting to date of first
 176 flowering was assumed. Rice seedlings were therefore grown on residual soil water (soil water
 177 reserve) until date of first flowering (2 to 7 weeks after planting, WAP). Thereafter irrigation
 178 was imposed weekly during reproductive growth (flowering to crop maturity: 8 to 16 WAP). In
 179 another set, second planting (January, 2011), rice seedlings were drip-irrigated weekly from
 180 planting to harvest. For both experiments, irrigation regimes consisted of water application at
 181 weekly intervals using drip irrigation system. In both experiments, irrigation was imposed using
 182 low-head (gravity) drip system weekly and fortnightly and 1.38 litres of water per plant at each
 183 irrigation. Irrigation water was applied using the gravity-drip irrigation system while water was
 184 delivered to plants via point source emitters of $2\frac{1}{4}$ l/h discharge rate. The emitters were installed on
 185 laterals per row of crop and were spaced $1\frac{1}{2}$ m apart. Irrigation buckets were suspended on 1 –
 186 1.5 m high stakes to provide the required hydraulic heads. Drip irrigation was applied using
 187 point source emitters and the emitters ($2\frac{1}{4}$ l/h discharge rate) were installed on laterals per row of
 188 crop. Irrigation buckets were suspended on 1 – 1.5 m (hydraulic heads) high stakes (IWMI,
 189 2002; Olufayo, personal communication).

190 Data collected were subjected to analysis of variance (ANOVA) while significant
 191 treatment means were separated using the Least Significance Difference (LSD) test at 5% level
 192 of probability. The second year experiments (December, 2011 and May, 2012) were set up

following the identical treatments and procedure of December, 2010 and May, 2011 experiments. There were no significant differences in the results obtained from year to year, and due to the similar yearly pattern of response of pepper to the soil moisture management strategies, the data for the 2 years of study were pooled and a 2-factor analysis of variance was carried out. Therefore, data collected for the two-years of study (2010 -2012) were averaged and means are presented in tables and figures.

RESULTS

Weather conditions of the site of study during rice growth.

Experiments were carried out during the dry season (December 2010 and May, 2011). The growing environmental condition of the dry season is characterized by high solar radiation intensities and temperatures (air and soil) and low relative humidity and high vapour pressure deficits and open water evaporation (Fig. 1a). The trends weather conditions during period of study (December 2010 and May, 2011) is presented in Fig. 1b and c. The Figures showed that during the course of rice growth and at different stages in the respective sowing dates December 2010 and January, 2011), rice plants were subjected to concurrent stresses of high temperatures, vapour pressure deficits and atmospheric demand (open/free water evaporation).

Soil moisture storage (replenishment) and depletion.

The values of soil moisture taken at 10cm depth differed for the first (residual soil moisture plus supplementary irrigation at reproductive growth) and second (irrigated crop from planting to harvest) sowing dates (Fig. 2a and 3a). For the December sown crop, the initial soil moisture contents were high possibly from the late rains of the second modal rainfall pattern which terminates about November and residual effects of the receding flood. The sequence of depletion and replenishment of soil moisture under first and second sowing dates (supplementary and full irrigation) are shown in Fig 2b and 3b. During the establishment and vegetative growth stages,

differences in soil moisture storage (replenishment via irrigation) were found. A general high soil moisture storage was observed within the first to the five weeks after sowing before the attainment of anthesis/heading dates. Thereafter, lower moisture was stored in the soil at reproductive phase (heading and seed filling period). The site of the experiment is a flood plain (fadama) characterized by shallow water table depths, capillary rise from the water table in addition to the residual moisture from the rainfall-enhanced floods can have influenced the soil moisture content (storage) within the rice plant root zone.

Growth, yield and yield components of rice.

Significant differences were observed for growth and yield parameters of cowpea in the different sowing dates (December and January). Among the rice varieties, differences were obtained in other growth phases such as 50% flowering date to seed filling and physiological maturity of seeds (Table 1 and 2). The selected rice varieties also had different maturity dates in particular, differences in the duration of reproductive growth phase.

Based on the parameters measured in this study, the Ekpoma (upland) variety is superior to the others (Upland Nerica 4 and lowland Nerica 1 and 2). Over other the Nerica varieties, significantly higher values of root dry weight, number of roots, root length, shoot dry weight, length and breadth of the flag leaf, flag leaf, number of tillers, panicle and seed weight were produced by the Ekpoma variety. However, the lowland Nerica varieties produced similar (non-significant differences) in plant height, number of leaves, spikes / panicle and spikelets / panicle, panicle and seed weight / panicle and harvest index (HI). The inherent potentials of the four varieties appeared to be remarkably expressed under full irrigation (January sowing date) than growth on residual soil moisture plus supplementary irrigation during reproductive growth phase (December sowing date). In the January sowing when rice plants were irrigated from planting to maturity, significant higher ($P < 0.05$) values of most of the parameters considered in this study were obtained.

243 There was considerable variation between the two groups of rice tested for growth and seed yield
 244 characters (Table 3). For example, the two best lines (Upland Ekpoma and Nerica 4), had similar
 245 yield performance when grown under irrigation from planting to maturity (harvest) but differed
 246 significantly in their trait combinations. The significantly improved performance of upland
 247 varieties (Ekpoma and Nerica 4) for the respective first and second sowing dates (Table 3), was
 248 associated with for example higher seed weight (2.9 & 7.6g compared with 2.0 & 5.1 g) and
 249 leaf area (68 & 96 m² compared with 42 & 52 m²). Genotypic potential can explain the variation
 250 for most of the measured traits (root and shoot, panicle and seed weights and harvest index). The
 251 results indicate that for most of the traits measured (root and shoot weight, leaf area, plant height,
 252 number of tillers, panicle and seed weight, 100 seed weight and harvest index), these parameters
 253 were significantly different between December (first) and January (second) sowing dates (Table
 254 4). Over December sowing, the yield advantage of the January sowing under irrigation
 255 throughout growth is associated with taller plants (103.4 & 76.8 cm), leaf area (76 & 52 m²),
 256 and shoot biomass (103.7 & 79 g), panicle weight (0.30 & 0.20 kg) and harvest index (8.9 &
 257 6.7). In addition, the seasonal sum of soil moisture depletion within crop root zone and
 258 efficiencies of water use (186 and 223 mm; 0.031 and 0.053 t/ha/mm) were higher for the
 259 January sown crop (Table 4).

260 Some of the measured growth and seed yield characters of rice were related with the prevailing
 261 weather conditions of the respective sowing (December and January) and regression equations
 262 (exponential, power, logarithmic) were fitted to into these relationships. The regression
 263 coefficients (R^2) which were mostly negative for these relationships differed for the two sowing
 264 dates differed, R^2 values were higher for the December sowing date for and higher for January
 265 sown rice for minimum temperatures (Table 5). Shoot biomass (tiller number and leaf area)
 266 correlated strongly with crop water satisfaction/stress index (CWSI; 1-ETa/ETo), accumulated
 267 heat units/thermal time and evaporative demand, minimum temperatures. Similarly, seed yield

268 were negatively and highly associated with evaporative demand and thermal time and minimum
269 temperatures.

270

271 **DISCUSSION.**

272 Experiments were designed to examine whether residual soil moisture storage of an inland flood
273 plain in the dry season can satisfy rice water requirement and the effects of deficit irrigation
274 scheduling strategies during the course of rice growth (vegetative or early reproductive growth
275 phases) on seed yield production. Four varieties of rice were field evaluated their yield
276 performance and related traits under variable soil moisture management strategies (residual soil
277 moisture at the vegetative stage supplemented with irrigation at the reproductive stage and full
278 irrigation schemes throughout growth phases. The aims were to understand genotypic adaptation
279 among rice varieties to the soil and growing environmental conditions of the dry season in inland
280 valley swamp (flood plain) in a humid rainforest zone of Nigeria. Among the tested rice
281 varieties, genotypic tolerance of the soil and air temperatures, moisture deficit stresses and
282 evaporative demand of the dry season was evaluated and the value of genotypic tolerance
283 attributes to seed yield production was discussed.

284

285 The dry season is characterized by negligible rainfall, low relative humidity, and high soil water
286 evaporation and solar radiation (high climatic demand). These environmental conditions are
287 known to affect biomass accumulation and seed setting and yield of rice (He et al., 2009;
288 Jagadish et al., 2010). In addition to the growing environmental conditions of the site of
289 experiment, the two sowing dates (December and January) and soil moisture management
290 strategies adopted (soil moisture replenishment via supplementary and full irrigation regimes)
291 produced changes in soil moisture storage, plant water extraction/depletion in the root zone.

292

The panicle weight and panicle contribution to seed yield (productive spikes and spikelets) appeared to be affected by root zone soil moisture status and growing weather conditions at heading (anthesis) and seed filling period. The high temperature and low relative humidity (high saturation vapour pressure deficit – SVPD) presumably aggravated soil water evaporation and the depletion of stored soil moisture, the resultant moisture deficit stress effect could have depressed dry matter accumulation and seed filling among the rice varieties evaluated. Irrigation ensure regular water supplies to meet the water demand of cultivated rice (Jagadish et al., 2010) which facilitated good vegetative growth and seed yield production. Full irrigation throughout crop growth during the second planting (January sowing) via enhanced soil moisture status, promoted growth and yield characters of rice and the effects were significant on seed yield production over supplementary irrigation. Irrigation is known to ameliorate the hydrothermal regimes of soil. Plant biomass (root and shoot dry weight) and leaf area were better under full drip irrigation strategy and the improved growth was accompanied by high grain yield and water use efficiency (WUE) (Agele et al., 2010; Jagadish et al., 2010). The tested rice varieties responded differently to supplementary and full irrigation strategies which is attributable to genetic potentials or characteristics which is also subject to the prevailing environmental variable at the different growth phases.

Drought is the most important factor limiting rice productivity under rainfed system worldwide and especially in the humid tropics. In this study, four varieties of rice were field evaluated their yield performance and related traits under variable soil moisture regimes (residual soil moisture at the vegetative stage supplemented with irrigation at the reproductive stage and full irrigation schemes throughout growth phases in the dry season in an inland flood plain (fadama). The study established the relationship between drought tolerance and yield potential among the tested rice varieties and possible mechanisms that functioned together to contribute to their improved drought tolerance and seed yield potentials. When compared with upland varieties,

lowland rice had significantly lower biomass and seed yields in addition to lower harvest indices. However, differences were not significant between the groups in terms of biomass and seed yields under full irrigated conditions. A possible mechanism is dehydration avoidance, characterized by significantly higher growth attributes and biomass accumulation across varieties and groups under stress and profound biomass accumulation under full irrigated conditions. Under full irrigated conditions all varieties were characterized by improved harvest index signifying efficient biomass partitioning, resulting primarily from heavier panicle and seed weight. These ascertions were true and can explain the high biomass accumulation and seed yield production in the Ekpoma variety, the best performing line. Considerable variation in the measured traits among the lowland and upland varieties implies differences in the degree of drought tolerance and yield potential

The most important mechanism contributing to drought tolerance of the improved upland and lowland Nerica lines was inferred to be dehydration avoidance, characterized by their significantly higher biomass under stress. This mechanism was reflected by their better abilities to maintain a high biomass accumulation under stress. The measured drought tolerant-related traits in the tested rice varieties which presumably are the underlying mechanisms functioned together and contribute to their improved drought tolerance and seed yield potentials. However, the contributions of these traits to drought tolerance and seed yield production in the upland and lowland rice varieties appeared to vary depending on specific period(growth phase) during growth which drought stress was experienced.

The measured drought tolerant-related traits in the tested rice varieties which presumably are the underlying mechanisms functioned together and contribute to their improved drought tolerance and seed yield potentials. However, the contributions of these traits to drought tolerance and seed yield production in the upland and lowland rice varieties appeared to vary depending on specific period(growth phase) during growth which drought stress was experienced.

Efficient biomass partitioning characterized by high harvest index (HI) can be attributed as the mechanism that contributed to drought tolerance and yield potential among rice varieties. characterized by higher harvest index (HI). This was consistent with previous reports that the maintenance or improvement of HI is of critical importance for drought tolerance (for grain yield) under terminal drought stress (Fischer *et al.*, 2003; White and Wilson, 2006; Monneveux *et al.*, 2008; Fukai *et al.*, 2009). The increase in HI under drought condition was most probably associated with a higher remobilization of assimilates to fill the grains. Previous studies showed that the contribution of dry matter partitioning from stems and leaves to grain filling increased with the severity of drought stress (Atlin *et al.*, 2004). The full irrigation applied in this study had greater effects on shoot biomass size (source supply) traits (plant height, leaf area, number of tillers), whereas supplementary irrigation greatly affected traits related to sink size and partitioning (panicle and seed weight, total number of seeds and harvest index).

The environmental conditions after the initiation of reproductive growth can change floral development, alter pollination, or prevent seed filling and ultimately seed yield in crops (Zinselmeier *et al.*, 1999; Pressman *et al.*, 2002; Sato *et al.*, 2002). In crops cereals in particular, unfavourable growing environment condition such as drought imposes assimilate limitation, restricts pollination and decreases kernel set (Uhart and Andrade, 1995; Zinselmeier *et al.*, 1999; Agele, 2006). In addition to the prevention of pollination presumably by low water potentials during grain filling can arrest ovary growth and cause embryo abortion (Pressman *et al.*, 2002).

Traits such as biomass accumulation, leaf area development (duration of canopy), capacity for assimilate reserve and mobilisation to reproductive structures (grain) are important to crop yield under variable soil water and thermal regimes (Timsina *et al.* 1993; San Jose *et al.* 2003). Plants possess traits which are important to the survival and productivity, these traits are also involved in setting tolerance limit to and confer increased productivity under variable weather conditions

(He et al., 2009; Jagadish et al., 2010). The identification and understanding of the values of these traits is important in the strategies to improve genotypic adaptation of crops in areas and seasons when varying degrees of soil moisture deficits and temperature extremes are encountered at some stages of crop growth cycle. The tested varieties exhibited differences in their sensitivity to the growing season environmental conditions. The greatest sensitivity occurred in the lowland Nerica varieties.

Regression equations were worked out between some growth parameters of cowpea and some weather variables. These relationships were characterized by variable regression coefficients (R^2) in the different sowing dates. The regression coefficients (R^2) show that on the average, about 40% of shoot biomass and seed yield production in rice is determined by minimum temperatures, open water evaporation, atmospheric dryness (vapour pressure deficit) and accumulated thermal time requirements during the growing period.

Conclusion

The results of this study demonstrated that the tested rice varieties (upland and lowland) differed for most of the traits (parameters) measured between the December and January sowing dates. Total seed yield (3.2 t ha^{-1}) was higher in January over December (1.24 t ha^{-1}) sowing in addition to higher water use efficiencies (0.053 & 0.031 t/ha/mm). The reductions in yield for December sowing is associated with reductions in leaf area, shoot weight panicle and 100 seed weight and harvest index across all tested lines. The two groups of rice tested differed in their growth and seed yield characters. For example, the two best lines (Upland Ekpoma and Nerica 4), had similar yield performance in both sowing dates) but differed in their trait combinations. The improved performance of upland over the lowland varieties for the respective first and second sowing was associated with an increased shoot biomass (6.5 and 4.5 g), increased seed weight (5.5 and 3.5 g) and HI (8.5 and 7.5). Over the lowland varieties, upland Ekpoma and Nerica 4

395 exhibited superior ability to produce tillers, panicle and seed weights. Some of the measured
 396 growth and seed yield characters of rice were related with the prevailing weather conditions of
 397 the respective sowing (December and January). The regression coefficients (R^2) which were
 398 mostly negative for these relationships differed for the two sowing dates differed. The strong
 399 negative association of CWSI with seed yield indicates the inability of soil moisture storage to
 400 satisfy rice water requirements (ETa).

401 In future climates, rice could more frequently be subjected to simultaneous high temperature and
 402 soil moisture deficit stress during sensitive developmental stages such as flowering and seed
 403 filling. Our results indicate that the examination of genotypic adaptation in terms of yield
 404 potential in addition to secondary traits under variable soil moisture regimes in the rootzone at
 405 the site of study are important for improving both drought tolerance and yield potential in rice in
 406 the various sowing seasons in humid tropical environment.

407 Four varieties of rice were evaluated for beneficial responses to multiple abiotic stress factors
 408 (soil and air moisture deficit and temperature stresses) via phenotyping cultivar attributes.
 409 Among the tested rice cultivars, lines with superior ability to produce tillers with significant
 410 contributions to seed yield under soil moisture limitations. In a cultivar, higher yield potential
 411 may be related to ability to tolerate multiple and concurrent abiotic stresses of soil and air
 412 moisture deficit and temperature stresses. Indigenous or land races of rice have wide
 413 adaptability and excellent grain quality, but moderate yield potential (low productivity) and high
 414 susceptibility to abiotic stresses such as drought and temperatures and problem soils

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561 Table 1. Growth and yield parameters of rice varieties grown in residual soil moisture in the dry
562 season in an inland valley swamp (December 2010 - May 2011)

Parameters	<u>Rice varieties</u>				LSD (0.05)
	Ekpoma (upland)	Nerica 4 (upland)	Nerica 1 (lowland)	Nerica 2 (lowland)	
Root dry weight (g)	3.07	0.94	0.74	0.57	0.40
Total No of roots	145.50	100.41	73.76	71.41	15.21
Total root length (cm)	723.04	291.17	302.22	288.18	43.24
Shoot dry weight (g)	4.17	1.55	1.20	1.08	0.54
Total plant fresh biomass (g)	18.13	13.99	17.59	14.86	4.60
Plant height (cm)	80.24	75.17	77.05	74.91	3.62
Stem girth (cm)	0.45	0.37	0.32	0.30	0.02
No of leaves@ 50% flowering	6.17	4.60	5.55	5.02	1.42

577	Leaf area / plant (cm ²)	70.25	53.88	41.01	42.30	24.62
578	Length of flag leaf (cm)	34.08	28.51	25.64	25.23	7.63
579	Width of flag leaf (cm)	1.82	1.53	1.39	1.26	0.08
580	No of productive tillers / plant	4.09	3.64	2.71	2.57	0.21
581	Heading date (50% flowering)	100	65	65	65	----
582	No of spikes / panicle	10.7	10.4	10.5	8.9	1.52
583	No of spikelets / panicle	111.55	83.45	67.55	63.50	18.7
584	Panicle weight / plant (g)	173	157	163	141	21.03
585	Seed weight / panicle (g)	3.40	2.46	1.91	2.10	0.36
586	Seed yield (t/ha)	1.70	1.23	0.96	1.05	0.21
587	100 seed weight / plant (g)	3.55	2.99	3.41	3.31	0.06
588	Harvest index (HI)	5.3	5.7	8.2	7.6	2.03

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592 Table 2. Growth and yield parameters of four rice varieties under full irrigation in the dry season

593 in an inland valley swamp (January 2011 – May 2011).

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595		<u>Rice varieties</u>				
596		Ekpoma	Nerica 4	Nerica 1	Nerica 2	LSD (0.05)
597		(upland)	(upland)	(lowland)	(lowland)	
598	Parameters					
599						
600	Root dry weight (g)	13.0	3.02	5.81	5.17	0.40
601	Total number of roots	400.1	352.3	208.9	209.3	15.21
602	Total root length (cm)	1680.9	1030.2	1079.8	1064.8	43.24
603	Shoot dry weight (g)	14.00	3.49	6.58	6.08	0.54
604	Total plant fresh biomass (g)	108.53	100.0	100.12	106.30	4.60
605	Plant height (cm)	127.9	106.9	88.8	70.2	11.9
606	Stem girth (cm)	0.5	0.42	0.27	0.28	0.02
607	No of leaves@ 50% flowering	15.43	14.95	10.48	11.10	1.42
608	Leaf area / plant (cm ²)	112.54	78.45	57.79	55.60	24.62
609	Length of flag leaf (cm)	40.74	35.36	30.36	31.74	2.74
610	Width of flag leaf (cm)	2.17	1.76	1.58	1.55	0.29

611	No of tillers/plant	4.40	3.93	3.75	3.78	0.21
612	Heading date (50% flowering)	100	73	70	71	----
613	No of spikes / panicle	13.4	11.6	12.4	10.7	1.55
614	No of spikelets / panicle	155.60	110.10	94.5	93.8	28.70
615	Panicle weight / plant (g)	275.4	233.7	268.2	236.8	23.4
616	Seed weight / panicle (g)	9.21	6.10	5.17	4.99	0.36
617	Seed yield (t/ha)	4.61	3.05	2.59	2.50	0.43
618	100 seed weight / plant (g)	3.50	3.22	3.22	3.09	0.30
619	Harvest index (HI)	8.6	9.1	9.3	8.8	1.17

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625 Table 3. Growth and yield of the upland and lowland rice varieties for December and January
626 sowing dates

Sowing dates	Root biomass (g)	Shoot biomass (g)	Leaf area (cm ²)	Plant height (cm)	Number of tillers per stand	Panicle weight (g)	100 seed weight (g)	Seed weight per plant (g)	Harvest index
December sowing date									
Upland varieties	2.1	2.8	68	79	3.8	223.3	3.3	2.9	6.95
Lowland varieties	1.3	1.7	42	76	2.6	195.4	3.4	2.0	7.40
LSD (0.05)	0.42	0.46	7.6	4.1	0.54	21.7	0.43	0.46	0.35
January sowing date									

Upland varieties	9.0	9.5	95.3	118.2	4.2	215.6	3.3	7.6	8.75
Lowland varieties	5.5	6.8	58.2	79.7	3.8	189.7	3.2	5.1	8.21
LSD (0.05)	2.7	2.3	17.7	22.6	0.33	14.8	0.31	1.63	0.71

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633 Table 4. Growth and yield of rice for December (first) and January (second) sowing dates

Sowing	Shoot biomass (g)	Plant height (cm)	Leaf area (cm ²)	Panicle weight (g)	Seed weight per panicle (g)	Number of seeds per panicle	100 seed weight (g)	Seed yield (t/ha)	Harvest index	Total water applied (mm)	Seasonal sum of soil moisture storage (mm)	Water use efficiency (mm/Kg)
First	79.30	76.84	51.9	0.15	2.47	10.8	3.32	1.24	6.7	40	186	0.031
Second	103.74	103.42	76.1	0.26	6.37	11.4	3.26	3.19	8.9	60	223	0.053
LSD (0.05)	9.31	12.42	9.7	0.05	0.8	0.04	0.03	0.67	1.43	----	----	0.003

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Table 5. Association of some weather factors with growth and yield characters of rice during its growth.

Parameters	Regression equations	R^2
<i>Seed weight and CWSI: First</i>	$y = -13.28x + 6.4$	0.94
<i>Second</i>	$y = -3.93\ln(x) + 1.31$	0.92
<i>100-seed weight and CWSI: First</i>	$y = -37.9x + 21.6$	0.95
<i>Second</i>	$y = 3.754x^{-0.72}$	0.81
<i>Seed weight and vpd: First</i>	$y = -4.251x + 6.4$	0.94
<i>Second</i>	$y = 1403.5e^{-0.02x}$	0.64
<i>100-seed weight and vpd: First</i>	$y = 5182.x^{-5.36}$	0.92
<i>Second</i>	$y = -21.08e^{0.412x}$	0.40
<i>Panicle weight and vpd: First</i>	$y = 123.7e^{-1.93x}$	0.90
<i>Second</i>	$y = 21.08e^{0.412x}$	0.57
<i>Leaf area and Thermal time: First</i>	$y = 123.7e^{-1.93x}$	0.90
<i>Second</i>	$y = -2353\ln(x) + 179$	0.73
<i>Seed weight and T minimum: Rainy</i>	$y = 0.103x^2 - 29.14x + 1472$	0.53
<i>Second</i>	$y = 855.8e^{-0.22x}$	0.64
<i>Panicle weight and T minimum: Rainy</i>	$y = -110\ln(x) + 347.8$	0.40
<i>Late</i>	$y = 0.01x^2 - 2.23x + 150.7$	0.71

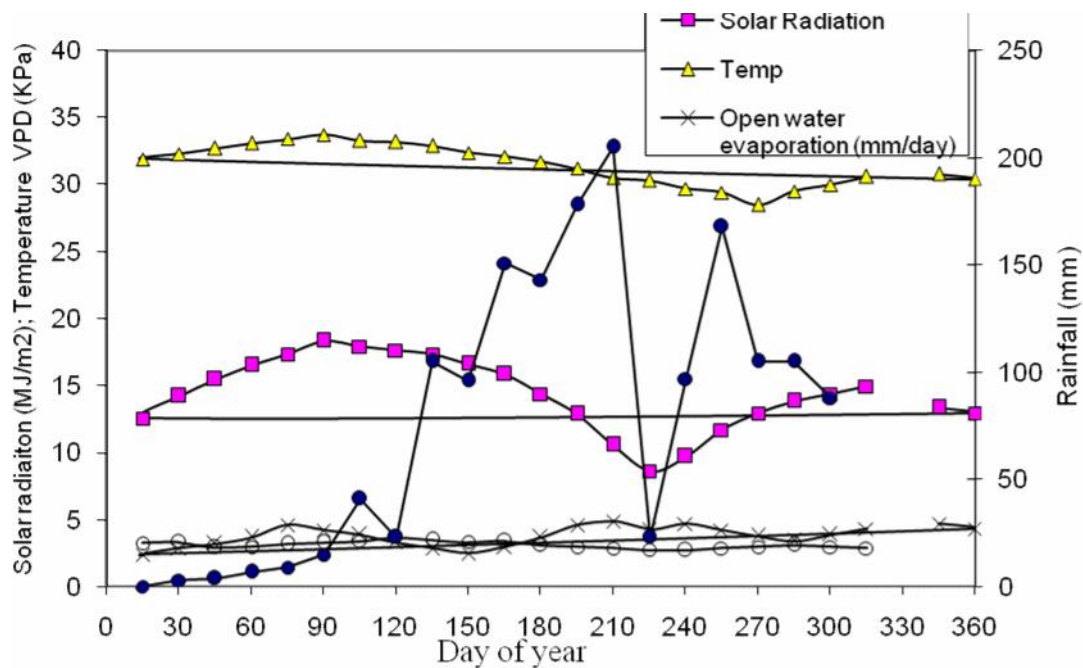


Fig. 1a. Some meteorological variables at site of experiment

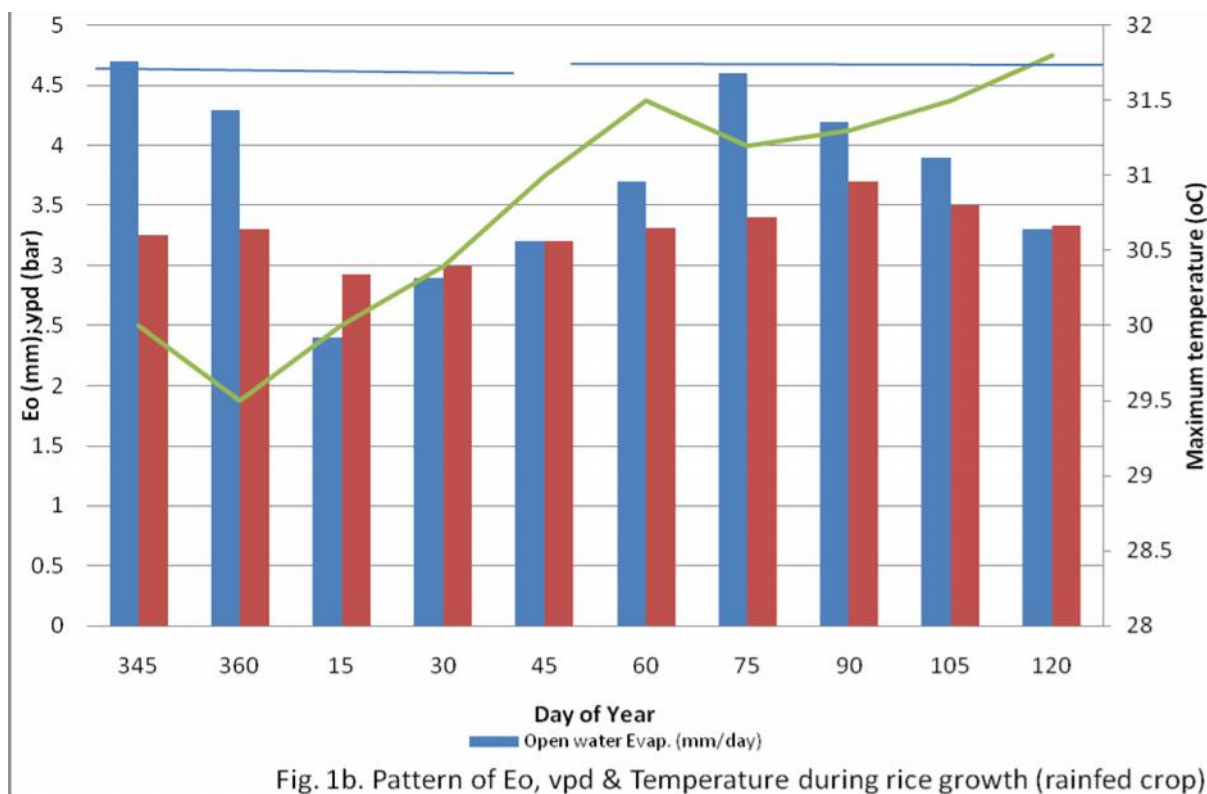
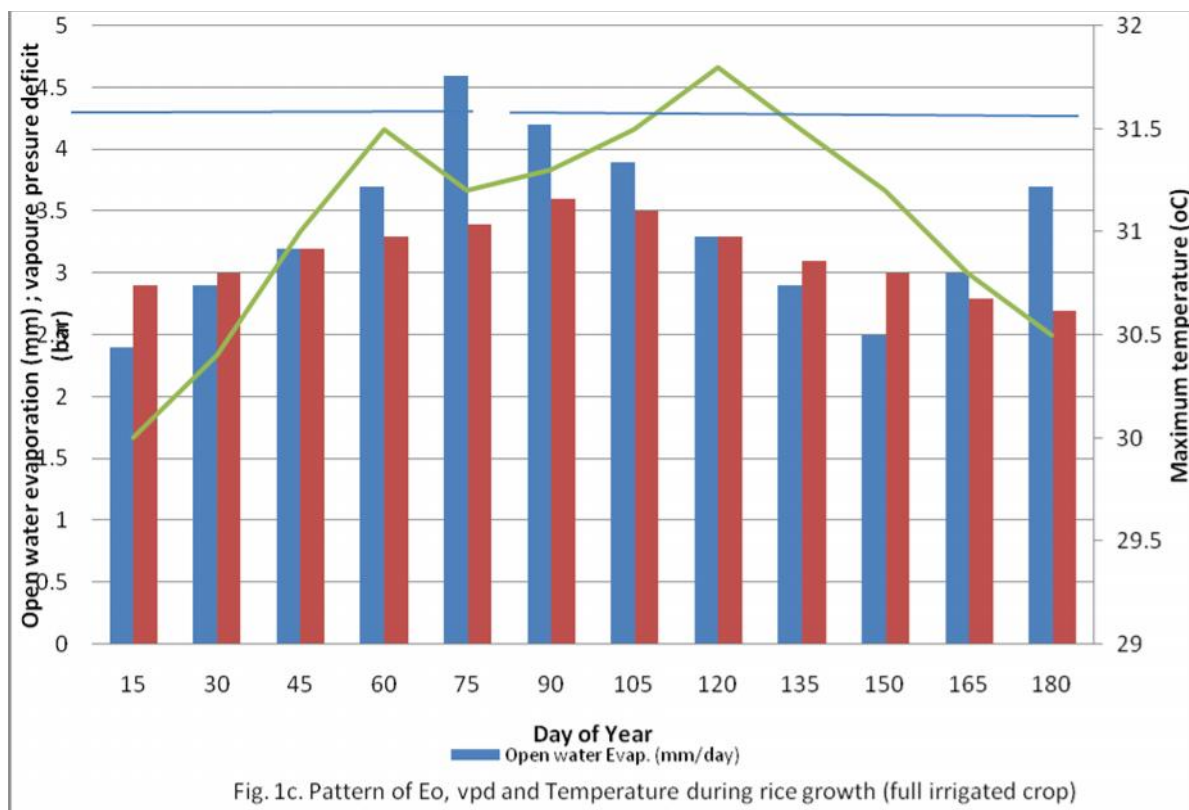
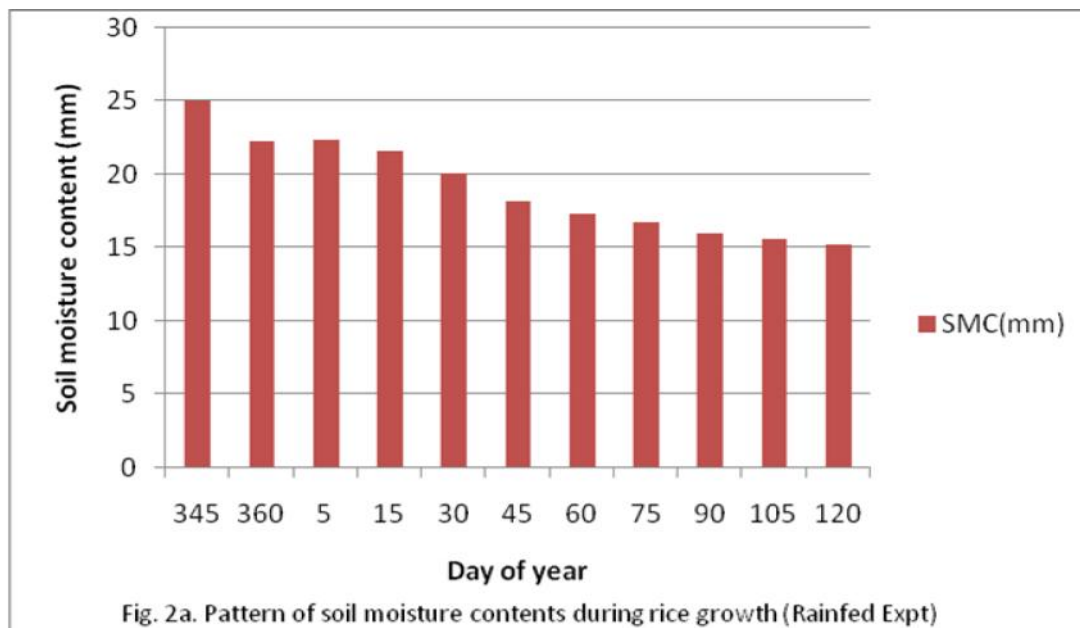


Fig. 1b. Pattern of Eo, vpd & Temperature during rice growth (rainfed crop)

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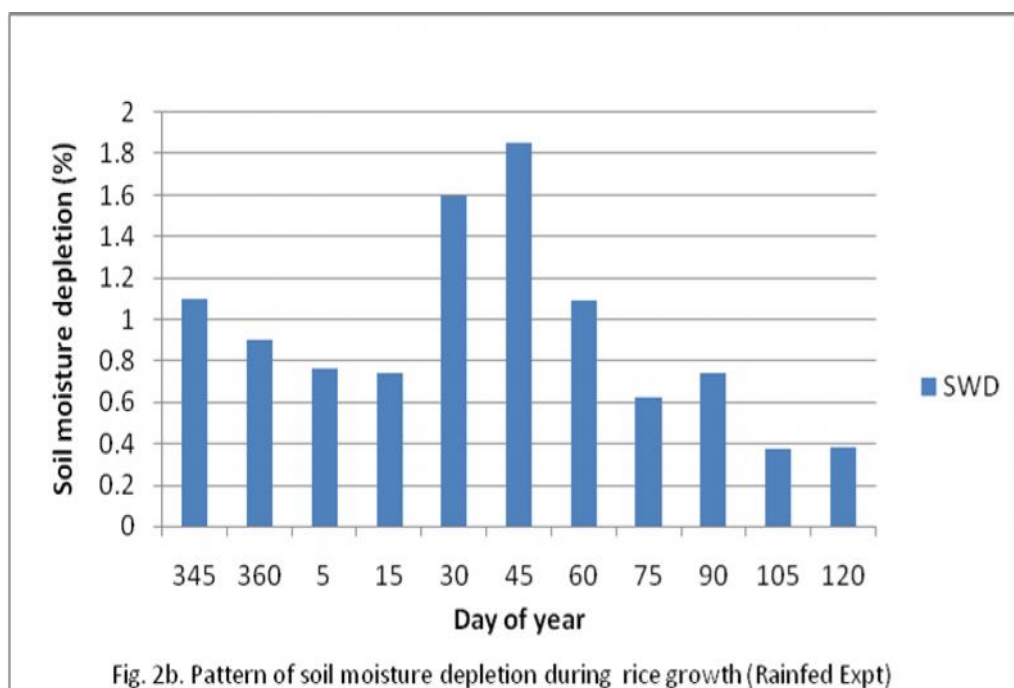


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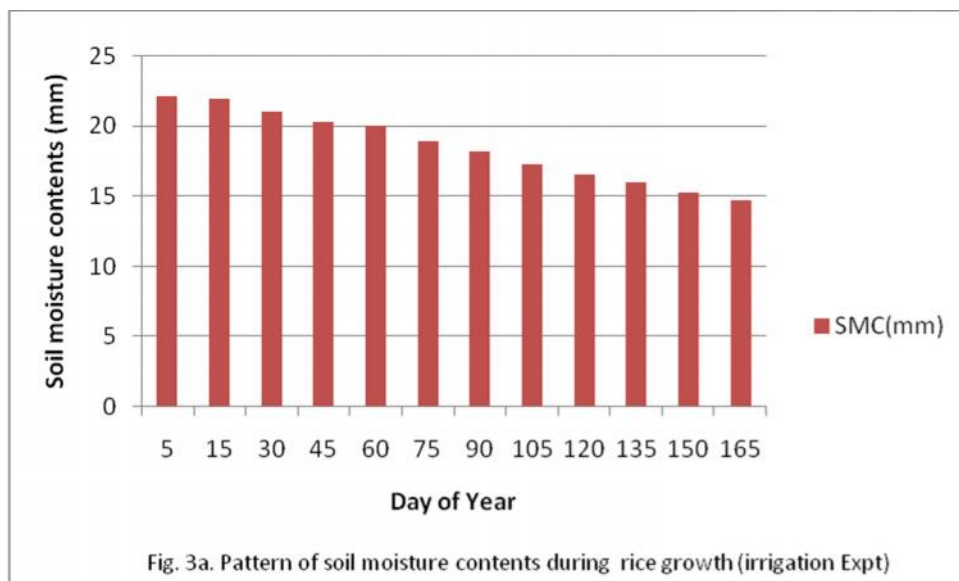


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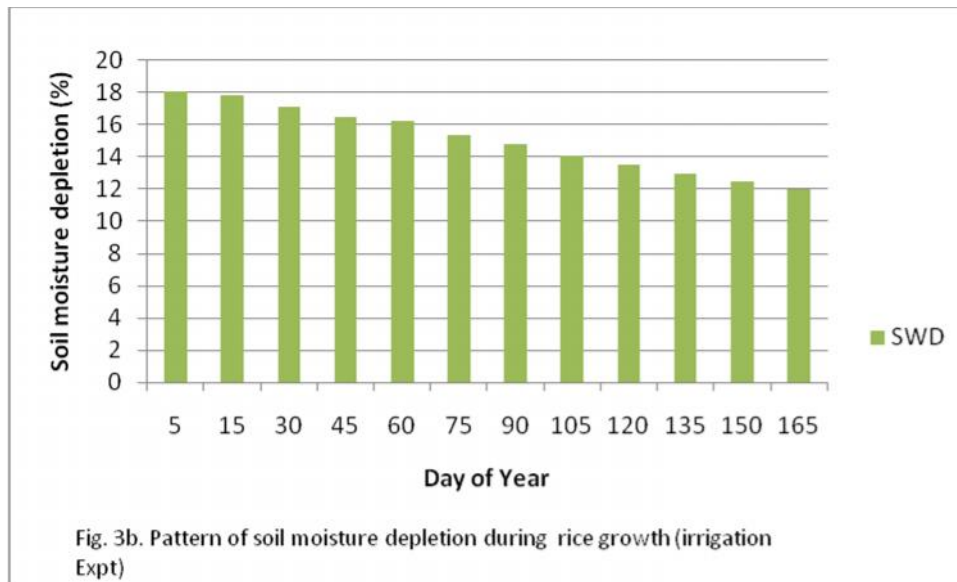


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