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Crop Waterstress Management in the Tropics and Subtropics (380c)

Physiological and agronomic responses of selected rice genotypes to irrigation management in the Sahel

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Abstract

As a result of population growth and industrial development, water scarcity is steadily increasing. Paddy rice production has a high water demand. The water consumption in paddy rice production accounts for a large share in variable production costs. Rising fuel prices decrease farmers´ profits due to pumping costs and contribute to the overall decrease in available water. There is a strong need to implement water saving production systems in rice production, such as Alternate Wetting and Drying (AWD), Intermittent Irrigation (II) and System of Saturated Soil Conditions (SSC). The SSC, avoiding a standing water layer in the field, was tested at the WARDA-Sahel-Station in the Senegal River Delta during the rainy season 2008. Ten cultivars with a broad genetic background were grown in SSC and results were compared to a Conventional Paddy System (CPS). The main objective was to find promising genotypes for SSC, thus, the responses of yield [kg m^{-2}], water use [mm], and accumulation of biomass [g m^{-2}], tiller number [number m^{-2}] and the phenological development in the SSC were studied. The SSC achieved the same yield (average yield of 0.52 kg m^{-2}) as the CPS with 24% less of water input resulting in higher water productivity [g grain m^{-2} mm^{-1}]. The number of tillers was higher in SSC after panicle initiation. A variation in the phenological development was observed in the SSC but it had no influence on yield. On average, there was no statistical difference in aboveground dry matter between both irrigation treatments. WAS 161-B 9-2 and Sahel 202 are very promising cultivars for SSC showing high water productivity, high yield and competitiveness against weeds due to an early vigor. Problems that should be addressed in future are spikelet sterility, which may be caused by heat stress, and the optimisation of measuring evaporation, transpiration and seepage for a better evaluation of water losses on field level. SSC could be a viable alternative to flooded rice production in the Senegal River Delta. Results of this experiment indicate that water input can be reduced, therefore variable costs for pumping, without affecting yield, if varieties bearing the appropriate traits are integrated in the overall water saving system .

Keywords: Biomass production, Phenology, Promising genotypes, Rice, SSC, Water use, Yield

Erklärung

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Isabel Schlegel

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Table of Content

List of Tables iii
List of Figures iii
List of Equations iv
1 Introduction 5
2 Hypotheses & Objectives 7
Literature review 8
3.1 Water and rice production 8
3.2 Water demands and losses at field level 9
3.3 Water saving productions systems 11
3.4 Problems and issues often related to drought stress 13
3.5 Rice production in Senegal 15
4 Materials and Methods 18
4.1 Experimental site and field conditions 18
4.2 Cultivars, experimental design and growth conditions 20
4.3 Irrigation treatments and water loss measurements 22
4.3.1 Conventional Paddy System 24
4.3.2 System of Saturated Soil Conditions 25
4.4 Observations and Measurements 25
4.4.1 Weather 25
4.4.2 Water treatments 25
4.4.3 Phenology 26
4.4.4 Sampling 26
4.4.5 Data processing and problems during cropping period 27
4.5 Statistics 28
5 Results 29
5.1 Water use 29
5.2 Crop duration and phenological development 36
5.2.1 Crop duration 36
5.2.2 Phenological development 37
5.3 Development of aboveground dry matter and tiller number 40
5.3.1 Treatment specific comparison 40

5.3.2 Comparison of genotypes 42
5.4 Yield components 47
6 Discussion 50
6.1 Water Use 50
6.2 Crop duration and phenological stages 52
6.3 Development of aboveground dry matter and tiller number 55
6.4 Yield, Harvest Index and Sterility 57
6.5 Promising genotypes 59
7 Conclusion & Outlook 61
References 63
Appendix 67
Curriculum vitae 87

List of Tables

Table 1: Characteristics of the cultivars used in the experiment. 20

Table 2: Description of lysimeters used in the experiment.....24

Table 3: Average water input (irrigation + precipitation) [mm], average yield [g grain m^{-2}] and calculated water productivity [g grain m^{-2} mm^{-1}].....29

Table 4: Water input [mm day^{-1}, irrigation and precipitation].....32

Table 5: Ratio of water input [mm irrigation and precipitation], Water productivity.....35

Table 6: Duration until maturity 36

Table 7: Means of standardised PI.....39

Table 8: Dry matter [g m^{-2}] 42

Table 9: Tiller number for each sampling date 43

Table 10: Yield [kg m^{-2}], Harvest Index and Sterility [%].....47

List of Figures

Figure 1: Daily records of temperature [C°], precipitation [mm] 19

Figure 2: Plot design.....21

Figure 3: Experimental layout.....21

Figure 4: Yield comparison [kg m^{-2}] 31

Figure 5: Yield [kg m^{-2}] over water input [mm] (irrigation and precipitation) 32

Figure 6a-d: Cumulative water input. 34

Figure 7a-c: Genotype specific duration.....38

Figure 8: Development of aboveground dry matter [g m^{-2}].....40

Figure 9: Number of tillers m^{-2}.....41

Figure 10: Aboveground dry matter (DM) [g $hill^{-1}$] development (standardised).....45

Figure 11a-f: Development of aboveground dry matter [DM g $hill^{-1}$] and Crop Growth Rate 46

List of Equations

Equation 1: Theoretical discharge through V-notch weir 23

Equation 2: Standardised Phenology.....27

Equation 3: Development of aboveground dry matter 27

Equation 4: Water savings [%] 29

Equation 5: Sterility [%] 48

Equation 6: Harvest Index.....48

1 Introduction

Rice (*Oryza sativa* L.) is the most important staple food for the majority of people all over the world. The worldwide rice production is estimated to cover approx. 154 million ha. 79 million ha of rice are grown under irrigated conditions with average yields varying between 3-9 t ha^{-1} (Maclean et al. 2002). To keep up with global population growth rice production must increase, but as the rice cropping area cannot be expanded the only remaining possibilities are within plant breeding and more efficient productions systems. Due to an increasing scarcity of input supplies, particularly the availability of water, these production systems must be environmentally sustainable.

Especially in conventional flooded rice production (paddy rice) is a need to cut down unproductive water losses. The two main problems rice producers have to deal with are an increasing demand for rice and an increasing scarcity of water. Therefore, major challenges are the reduction of water use and an increased water productivity (Bouman et al. 2005).

Recently, Sub-Saharan Africa is confronted with rising fuel prices, resulting in high costs for pumping and thus increasing the base costs of rice production. Since water is essential for living (e.g. cooking and daily needs) changing to water saving techniques in agricultural production would be advantageous. In addition, it is very important to develop management policies for the efficient operation of irrigation systems and providing economic incentives to farmers to reduce non-productive water losses (Maclean et al. 2002). Worldwide water saving production systems are already in use or being tested, such as Intermittent Irrigation, Alternative Wetting and Drying, and Saturated Soil Conditions (Boonjung et al. 1996; Borrell et al. 1997; Bouman et al. 2001; Tabbal et al. 2002).

Because of the tolerance to submerged growth conditions a highly productive cultivation of rice is possible. The special physiology and thus adaptation of rice may turn into a disadvantage when the system is provided with less water. Therefore specific traits such as high water productivity, drought resistance, low transpiration rate and a high competitiveness against weeds (especially in the beginning of the cropping period) are beneficial to achieve good yields in saturated conditions. In non-ponded water conditions the top

soil will oscillate between aerobic and anaerobic conditions, therefore it is likely that the weed pressure increases and micro climate within the field changes (increase of soil and root zone temperature), as well as the nutrional status of the soil.

An experiment was conducted to compare the System of Saturated Soil Conditions (SSC) and the Conventional Paddy System (CPS) in rice production at the WARDA-Sahel-Station (Ndiaye) in the Senegal River delta in the North of Senegal. Ten rice cultivars were grown under both conditions to study physiological and agronomic responses and to identify promising genotypic traits or cultivars for the SSC.

2 Hypotheses & Objectives

Ten cultivars with diverse origins and characteristics were grown using two irrigation methods: a conventional flooded system (CPS) (submerged soil) and the System of Saturated Soil Conditions (SSC) (no ponded water layer) as water saving production system. Water use and genotypic responses to the SSC were studied such as agronomical and phenological development compared to the CPS. Main focus was to pre-select promising genotypes for the SSC with traits which assure a good performance under saturated conditions. These traits are for example good water productivity, low transpiration rate, early vigor and a good remobilisation force, assuring high yields.

The following hypotheses were adopted:

- SSC requires less water input than the CPS at the same productivity level.
- Productivity in the SSC depends on genotypic performance in water limited conditions and how i.e. crop duration, biomass accumulation rate, and yield and yield components are affected by these conditions.
- SSC effects biomass accumulation and yield, and causes variations in phenological development.

Literature review

3.1 Water and rice production

Agricultural industry is a major water consumer, mainly due to irrigation. Therefore, it is of high importance to manage water consumption in a sound way. In contrast, the availability of water is steadily decreasing through pollution and resource depletion (Bouman et al. 2001). Water pollution results from the inappropriate application of mineral fertilisers, pesticides and herbicides. Through leaching and surface runoff contaminated water seeps into groundwater and flows into rivers. Long standing surface water which evaporates can cause salinisation of water and soils. Another problem caused by high water inputs in agriculture is the overexploitation of tube and shallow wells (Maclean et al. 2002).

Rice is a staple food for the majority of people; almost half of the world`s population depends on this crop. It is the most important food grain for most of Asia and plays a key role in the nutrition of many people in the tropical regions of Latin America and Africa (Maclean et al. 2002). To produce 1 kilogram of rice, which is generally cultivated as paddy rice, 2-3 times more water is needed compared to other cereals such as wheat (*Triticum aestivum* L.) (Barker et al. 1998). Rice can be cultivated as rainfed crop in uplands (dry rice) or in lowlands (ponded water layer) (Bouman et al. 2007). Irrigated lowland rice also named paddy rice is the predominant rice production system. Lowland production is characterized by bunded fields, conventionally puddling and transplanting. Puddling means harrowing under shallow submerged conditions, mostly done for weed control and to reduce soil permeability and percolation losses (Bouman et al. 2007). Paddy rice cropping represents a system in which the soil is continuously flooded. The ponded water layer ensures weed control and protects the crop from drought stress. The disadvantage of this system is the high demand for water that can lead to higher production costs due to higher expenses for fuel to run irrigation pumps or problems mentioned above.

Rainfed lowland rice production is prone to higher risk of crop failure in regard to timing, duration and intensity of rainfall. Whereas in paddy rice the continuous flooding helps to control weeds and pests, upland rice is mainly produced under dryland conditions with

neither irrigation nor puddling in usually non-bunded fields (Bouman et al. 2007). In Latin America and West Africa upland rice culture is predominant (Maclean et al. 2002). Especially in arid and semi-arid regions of the world the scarcity of water as a resource is the major determinant of successful rice production.

3.2 Water demands and losses at field level

The total seasonal water input varies from only 400 mm in heavy clay soils with shallow groundwater tables that supply water for crop transpiration by capillary rise to more than 2000 mm in coarse textured (sandy or loamy) soils with deep groundwater tables (Bouman et al. 2001). According to Yoshida (1981) normal water consumption in a rice cropping period is around 1240 mm up to 3000 mm.

The water losses in rice production are caused by evaporation, transpiration, percolation, seepage and overbund flow. Transpiration is the only productive water loss, whereas seepage, percolation, overbund flow, and evaporation are all non-productive water flows and can be considered as loss flows at field level (Bouman et al. 2007).

Evaporation is the release of water into the air as vapour from ponded water or from the surface of the soil; it varies with the surface coverage ratio of the field. More surface coverage alters the ratio between evaporation and transpiration. The more surface coverage the more transpiration and the less evaporation (Peng et al. 1994).

Transpiration is the release of water as vapour from plant surfaces. It is controlled by the opening and closing of the stomata, and is related to factors such as leaf area index, wind speed, temperature, solar radiation and moisture providing capacity of the soil (Peng et al. 1994). Rice leaves are generally thin, with no differentiation of mesophyll cells into palisade and spongy parenchyma. The number of stomata is tenfold greater than in leaves of dryland grasses. Rice cuticles are thin with a very thin wax layer and comparatively low cuticular resistance (Bouman et al. 2007). Therefore, rice is extremely sensitive to water shortage: when soil water content drops below saturation, growth and yield formation are affected (Yoshida 1981; Bouman et al. 2001).

Percolation describes the vertical flow of water below the root zone; whereas seepage describes the lateral subsurface flow of water (Bouman et al. 2007). Percolation and seepage depend especially on soil structure, hydrological and geological conditions and the irrigation technique, which indicates that they vary according to the regulation of the soil moisture content (Peng et al. 1994). In a heavy clay soil there is less percolation than in a sandy loamy soil (Bouman et al. 2001). Seepage and percolation can account for a large share of the seasonally required water on field level. Additionally, water loss through overbund flow can occur.

As already mentioned water scarcity is steadily increasing, as is the need to produce more rice. In the future less water will be available for agriculture; hence, a severe demand for water saving agricultural approaches is imminent. There are different approaches to produce rice with less water. These are genotype-specific improvements towards drought resistance by breeding, altering cropping techniques e.g. switching from transplanting to direct seeding (Tabbal et al. 2002; Wassmann et al. 2009) or simply by improving irrigation cannels, land levelling, puddling and tillage as well as proper bunds.

Tabbal et al. (2002) proposed the method of direct seeding instead of transplanting. Quite often transplanting implies irrigating the entire field to prepare the seedbed, which then only takes a small part of the field. Additionally the transplanting shock prolongs crop duration. Direct seeding can lead to water savings; it shortens field preparation and, therefore, water input may be smaller. Puddling is also seen as a water saving method, it increases water retention and the reduction of soil permeability, additionally it eases field levelling and transplanting (Tabbal et al. 2002). Every measure that shortens the cropping period or minimizes land preparation increases water productivity.

Breeding pursued different approaches, e.g. cultivars for non-paddy environments or short duration cultivars. The WEST AFRICA RICE DEVELOPMENT ASSOCIATION (WARDA) introduced *Sahel 108* as a short duration cultivar in the mid-1990s, which quickly occupied large areas of the rice cropping area in the Senegal River Valley – one third in the wet season and two third in the dry season, respectively (Maclean et al. 2002).

In terms of water scarcity other rice production systems than paddy rice have been developed. These are for example the System of Rice Intensification (SRI), Intermittent Irrigation (II), Alternate Wetting and Drying (AWD), Saturated Soil Conditions (SSC) or aerobic rice. The different systems, their characteristics and requirements will be explained in the following section.

3.3 Water saving productions systems

Less standing water in water saving production systems results in a lower water head, thus, in less seepage and percolation. Additionally, the absence of a water layer results in no evaporation from water surface (Borrell et al. 1997). Therefore, possible savings in production costs and higher water productivity can be achieved. Possible penalties in these systems can be: decreased biomass, yield reduction, more weeds, soil cracking, and the need for adopted varieties as well as a possibly higher workload.

In the system of Saturated Soil Culture (SSC) no water layer should occur on the soil surface. The moisture content in the root zone layer is taken as control criterion to determine the date and quota of irrigation, which is required as soon soil moisture content falls below 60-70% of saturation. In SSC soil pores are full of water (Peng et al. 1994). The SSC was first developed for soybean (*Glycine max*) by Hunter et al. (1980) in combination with furrow irrigation. According to Bouman et al. (2007) it represents a combination of paddy rice and upland rice production. In practice a shallow water layer is applied after reaching the critical lower soil moisture limit. Analyzing a data set of 31 published field experiments with a SSC-treatment Bouman et al. (2001) found that water input decreased on average by 23% (range: 5-50%) compared to the continuously flooded control, with a non-significant yield reduction of 6%. Borrell et al. (1997) experimented with raised beds (120 cm wide, with furrows of 30 cm width and 15 cm depth) to facilitate SSC practices. The water in the furrows kept the beds at saturation. Compared to flooded rice treatments, water savings were 34% and yield losses 16-34% (though not always significant). Tabbal et al. (2002) reported slightly lower yields for the SSC, but due to decreased water input, water productivity, but also the amount of weeds increased. Obermueller et al. (1974) found that within the SSC puddling improved growth and yield of unflooded rice. Water savings

vary between 20-40% (compared to paddy rice) depending on the different factors mentioned above (Peng et al. 1994; Borrell et al. 1997; Bouman et al. 2001; Tabbal et al. 2002).

In the Alternate Wetting and Drying-system (AWD) irrigation is managed in intervals, so that there is a change between flooded and non-flooded soil conditions. These periods can vary from one to ten days depending on the specific management regime, as well as on soil and climatic conditions. The success of this system depends strongly on the soil type. It is seen as a promising possibility for lowland rice areas with heavy soils and shallow groundwater tables. In loamy or sandy soils with deep groundwater high amounts of water can be saved (up to 50%) but at the expense of yield (up to 20%) (Wassmann et al. 2009). Bouman et al. (2001) stated that 92% of the AWD-treatments resulted in 0-70% yield reduction compared to the flooded controls. Overall AWD increased the productivity of total water input because the reduction of water input was higher than the reduction of yield. But unproductive water losses cannot be fully avoided because the soil is under submerged conditions at irrigation periods and, therefore, water consumption is still high (Belder et al. 2003).

The Intermittent Irrigation-system (II) is similar to the AWD-system. The concept favours flushing the soil at certain intervals after the water has disappeared from the surface. According to Lu et al. (2000) II-systems needed irrigation when the soil water potential decreased to values between 0-20 kPa at a depth of 5 cm. This procedure reduced the percolation rate by reducing the hydraulic head of the ponded water; however it lead also to a shrinking and swelling of the soil. The occurrence of rapidly soil cracking increases with prolonged drought periods.

Aerobic rice grows under non-flooded and non-saturated conditions; hence, water losses such as seepage, percolation and evaporation from water surface are eliminated. For aerobic rice production special cultivars are required (Wassmann et al. 2009). At the International Rice Research Institute (IRRI) scientists developed high-yielding tropical rice cultivars which can be grow in non-paddy environments (Maclean et al. 2002). IR 64, for example, has been developed as an early heading type providing suitable breeding materials for water saving rice cultivation (Farooq et al. 2009). Water use can be reduced up to

60% relative to that in lowland rice and is facilitated by the availability of weed management tools and seed-coating technologies. Additionally, less labour is required and it can be highly mechanized (Huaqi 2003). Problems which often can be found in upland rice production are high weed infestation, reduced nutrient availability, drought and heat stress, thus, possible yield penalty (Farooq et al. 2009).

The groundwater table plays an important role with regard to irrigation. The shallower the water table the less irrigation is needed, because the plants can satisfy their water requirements by using the groundwater. Additionally percolation is rather low in fields with a shallow water table (Tabbal et al. 2002). Probably water saving technologies may lower the groundwater table, thus leading to higher percolation rates.

An important factor for considering water saving systems is water productivity. This denotes the amount of marketable grain produced for each volume of water used for transpiration, evapotranspiration, irrigation, or rainfall (Bouman et al. 2007). Water productivity is higher the more yield is obtained or the less water is used or lost (Bouman et al. 2005). Values for water productivity vary according to site and irrigation system. Tabbal et al. (2002) found for a SSC-experiment an increase of water productivity of about 45% compared to flooded conditions. In II water input could be reduced even more but at the expense of increased yield loss. Bouman et al. (2001) achieved in a SSC-treatment mean water savings of 23% with an expense in yield of 6%. Water productivity increased in the experiments up to 1.9 g grain kg^{-1} water compared to 0.2-0.4 g grain kg^{-1} water in India and 0.3-1.1 g grain kg^{-1} water in continuously flooded rice in the Philippines. But it is very important to note that in most cases the increase in water productivity is directly related to a decrease in yield. Management strategies such as weed management, irrigation method, land levelling, as well soil type have a high influence on water productivity (Farooq et al. 2009).

3.4 Problems and issues often related to drought stress

Arguments pro paddy rice production are various. The most important ones are that in flooded systems no water stress occurs and a better weed control is possible, therefore higher yields can be obtained (Borrell et al. 1997).

In production systems with a reduced water input several problems can arise, and with an increasing reduction of water the detrimental effects on rice can increase too (Farooq et al. 2009). Risks are e.g. reduced biomass production, alteration in phenological development, yield reduction, and an increase in spikelet sterility. In the field it can lead to an increased weed infestation and soil cracking.

Several authors reported reduced tiller numbers and biomass production, resulting in a lower leaf area index, less photosynthesis and earlier senescence, all these facts leading to yield reduction (Heenan et al. 1984; Bouman et al. 2001). Boonjung et al. (1996) reported a critical period between panicle initiation (PI) and anthesis during which water deficits severely affect yields. In contrast, in experiments conducted by Borrell et al. (1997) similar yields were obtained in SSC-treatments compared to flooded conditions.

Under drought stress the plant cannot maintain surface cooling via transpiration, e.g. in the panicle, thus in addition the plant suffers from heat stress which can lead to an increase in spikelet sterility, especially when temperature exceed 35°C around anthesis (Yoshida 1981; Dingkuhn 1995; Bouman et al. 2001; Wassmann et al. 2009) Productivity increases with rising temperature, but declines due to heat stress when temperatures exceed the optimal range, which is between 23-26°C for rice (Dingkuhn et al.). Therefore, biomass production can decrease, whereas spikelet sterility increases with increasing temperature (Oh-e et al. 2007).

Reduced water supply before anthesis influences development as it may delay tillering, panicle initiation and anthesis, whereas after anthesis it can accelerate the development by rapid leaf senescence (Heenan et al. 1984; Boonjung et al. 1996). Lilley et al. (1994) observed delayed panicle initiation, as well as a prolonged panicle development in a water-deficit treatment.

Due to the inexistent water layer a higher population of weeds is possible. Borrell et al. (1997) described a negative correlation between water input and weed population. Additionally the absence of floodwater decreases the effectiveness of herbicides due to a rapid breakdown through light and temperature, which enhances weed population additionally. Borrell et al. (1997) found more weeds in a SSC than in a paddy system for a wet season

crop. Similar results were confirmed by De Datta (1981) who found a decreasing number of weeds by increasing floodwater depth.

When a paddy soil dries out cracking occurs with the severity depending on the soil type. Heavy clay soils are very susceptible to cracking. Cracking injures root systems and additionally leads to a higher percolation rate. With an increasing crack depth the amount of water infiltrating into the subsoil during irrigation or a rainfall event increases, leading to non-productive water losses. Lu et al. (2000) reported that water consumption was higher in an II-system compared to a SSC, mainly due to higher soil cracking. The avoidance of soil cracking is therefore a method for water conservation.

In view of the problems related to water saving techniques it is very important to find ways and solutions to overcome these issues because there is a strong demand for rice production that, on the one hand, uses less water and, on the other hand, achieves high yields to fulfil future needs for an adequate nutrition worldwide.

3.5 Rice production in Senegal

Sub-Saharan West Africa is increasingly susceptible to unpredictable extreme weather events such as long droughts or heavy rainfall. Results of these events are soil degradation and erosion, crop failure, rural poverty, mal- and undernourishment. Since 1973 the preference for rice in West Africa is constantly increasing. The regional demand for rice has grown about 6% annually by a combination of population growth and substitution of traditional cereals such as sorghum (*Sorghum bicolour*) and millet (*Panicum miliaceum*). Rice has become a major source of calories and the share of rice in consumed cereals has grown from 15% to 25% from 1960-1990. The rapid increase in demand was not met by the increase in production, consequently imports were required to satisfy food needs (Maclean et al. 2002).

Senegal is located in West Africa, bordering the North Atlantic Ocean, Mauritania, Mali, Guinea, Guinea-Bissau and the Gambia. Senegal has an area of about 197,000 km² and a total population of 12 Mill. From this area 12% (26,000 km²) are under agricultural use (FAO 2006). The value added from agriculture to the Gross Domestic Product was about 14.7% in 2007. Approx. 7 Mill people are living in rural areas (FAO 2006). Main crops are

millet, sorghum, maize and rice. In the commodity ranking list in terms of production, paddy rice was at the 5th place in 2005, behind groundnuts, millet, cattle and chicken meat (FAO 2005). In 2007 80,000 ha of paddy rice have been harvested with an average yield of 3 t ha^{-1} (FAO 2007). The food consumption quantity was 115 kg rice per capita in 2003 (FAO 2003). Senegal depends strongly on imports to meet rice consumption. In 2006 about 700,000 t of rice were imported to Senegal (mostly from Thailand and South-America) and 100,000 t were exported (mostly to Mali, the Gambia and Spain) (FAO 2006). A large share of the Senegalese agriculture, especially rice production, is irrigated. The area equipped for irrigation is approx. 120,000 ha (FAO 2002).

There are mainly two production seasons for rice. The main season starting in June with harvest in October-December, the off-season starting in February/March with harvest in June. The main production constraints to a sustainable rice production are according to Maclean et al. (2002):

- Heat-induced sterility at the end of the off-season in irrigated areas
- Cold-induced sterility in December
- Poor maintenance of irrigation facilities
- Inadequate and irregular input supplies such as seeds, fertilizer and credit
- Lack of small farm equipment, especially for post-harvest operation
- Lack of well-implemented rice policy
- Weak research and extension support
- Shortage of water in the dry season

The agricultural water withdrawal is about 93% of total water withdrawal in Senegal (FAO 2002). In the south of Senegal the largest share of agriculture is concentrated in the rainy season, but in the north, where rainfall is much lower, agriculture is strongly depending on irrigation either from groundwater or fresh water (e.g. from rivers) in both seasons.

Häfele et al. (1999) reported, the total area for irrigated rice culture in the Senegal River Delta amounts to ca. 70,000 of which 40,000 ha are under cultivation (SAED 1996, personal communication). Two main types of irrigation systems can be distinguished: (i)

formerly state-governed irrigation schemes with good irrigation and drainage infrastructure (10,000 ha) and (ii) private irrigation schemes without drainage (ca. 30,000 ha). The actual area under irrigation varies strongly from year to year.

For the cultivation of rice input supplies such as seeds, fertiliser and credit are needed, but as already mentioned above these supplies are often limited. Hence, rice production systems requiring less input supplies, e.g. fertilisers or credit, are needed. Due to the fact that irrigation often requires pumping of water, money and also water could be saved with water saving production systems such as SRI, AWD or SSC. At the WARDA-Sahel-Station in Ndiaye in the north of Senegal experiments have been conducted to observe the implementation of such water saving systems (AWD-Michel de Vries, SRI-Timothy Krupnik). Yet no experiments for the SSC were conducted.

The aim of the experiment, which was the background for this thesis, was to test a SSC in a Sub-Saharan environment and to evaluate different agronomical parameters related to rice production and genotypic performance.

4 Materials and Methods

4.1 Experimental site and field conditions

This study was conducted in Senegal, which is considered to be representative for irrigated rice production in the Sahel Zone. The experiment was conducted at the WARDA research station in Ndiaye (16°14’ N, 16°14’ W), 35 km northeast of Saint-Louis. Ndiaye is located in the Senegal River delta and has an arid coastal, strongly seasonal climate.
Senegal is situated on the West-African coast, in the transition zone from the Sahel to the humid savannas. Senegal has two main seasons: the wet season, which lasts from July to the end of October, and the dry season from November until June.

The dry season is characterized by high diurnal temperature amplitudes, minimum temperatures around 10°C in the early season (January) and maximum temperatures up to 40°C in the late season (June) (Dingkuhn et al. 1995). From November to March dry and dusty winds from the Sahara (Harmattan) are predominant. In the hot rainy season temperatures are between 22-40°C with southerly winds from June until October; most of the precipitation falls from July to November (Asch 1997). The average annual precipitation in Senegal is approx. 686 mm per year with 200-500 mm in the north and up to 1500 mm in the south (FAO 2005).

The soil in Ndiaye is a hydromorphic, strongly shrinking Hollalde-type vertisol with 47% clay, 14% sand, 39% silt (Le Brusq 1980). The groundwater table was approx. 50cm below soil surface.

The experiment was conducted in the hot rainy season of 2008, starting on July 10, 2008.

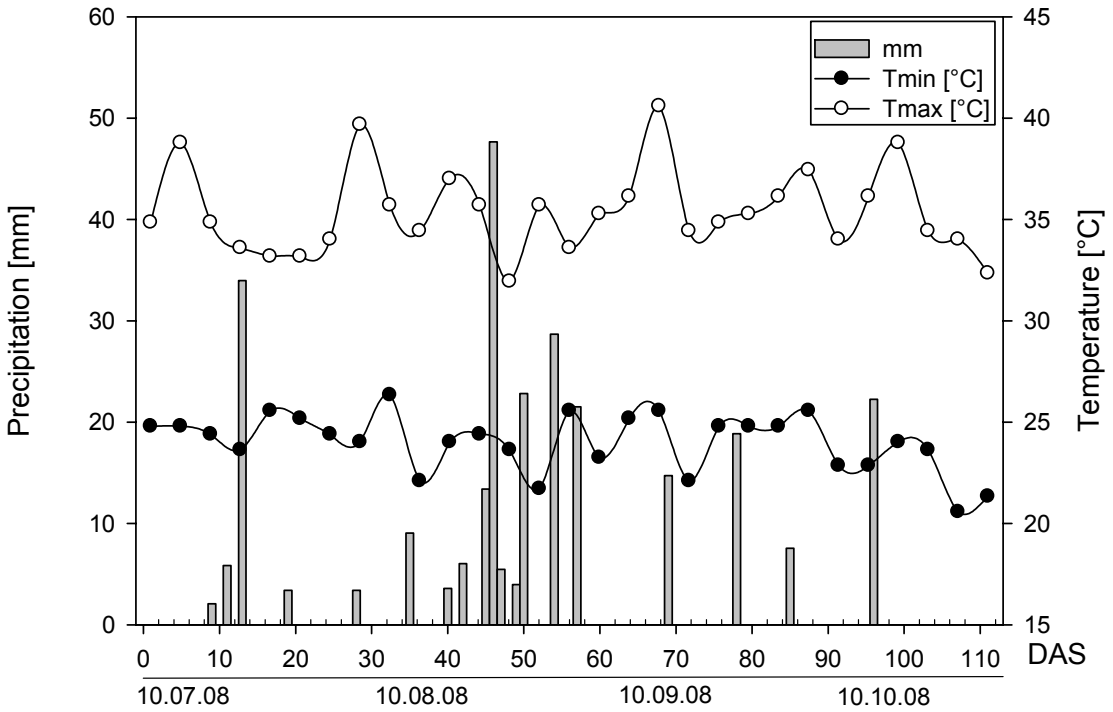

Figure 1: Daily records of temperature [C°] (automatically recorded by a meteorological station close to experimental site) and precipitation [mm] (measured with a rain gauge next to the plots) in the rainy season 2008 at the WARDA-research station in Ndiaye; DAS=Days after sowing, sowing: 10th of July

During the cropping period the average temperature was about 29°C and 274.25 mm of precipitation was measured (Figure 1).

4.2 Cultivars, experimental design and growth conditions

The aim of the experiment was to compare genotypic responses to two different irrigation treatments: the Conventional Paddy System (CPS) and the system of Saturated Soil Conditions (SSC).

10 rice varieties were used, covering a broad range of genetic diversity, such as long- and short-duration, photosensitivity, sensitivity or tolerance to diverse abiotic stresses; additionally local and international check varieties were included in the experiment (Table 1).

Table 1: Characteristics of the cultivars used in the experiment. Abbreviations: sat=*Oryza sativa;* gla=*Oryza glaberrima*; Impr=improved; Trad=traditional.; cultivars listed in alphabetical order

Cultivar	**Species/ Subspecies**	**Type**	**Duration**	**Special Property**	**Country of Origin**	**Potential Yield t ha^{-1}**
CG 14	gla	Trad.	short	upland	Senegal	-
Chomrong	sat/jap	Trad.	short	cold tolerant	Nepal	-
IR 31785-58-1-2-3-3	sat/ind	Impr.	short	salt sensitive, heat tolerant	Philippines	10
IR 4630-22-2	sat/ind	Impr.	medium	salt tolerant	Philippines	8
IR 64	sat/ind	Impr.	short	internat. check	Philippines	10
JAYA	sat/ind	Impr.	medium	heat tolerant	India	12
Sahel 108	sat	Impr.	short		Philippines	10
Sahel 202	sat/ind	Impr.	medium		Nigeria	12
WAS 6322	sat	Impr.	short	water saving	Senegal	10
WAS 161-B 9-2	satxgla	Impr.	medium		Senegal	10

For simplicity, IR 31785-58-1-2-3-3 will be abbreviated as IR 31785, IR 4630-22-2 as IR 4630 and WAS 161-B 9-2 as WAS 161.

The experimental site was separated into two blocks, which were irrigated differently. Each block consisted of three replications containing ten plots for the individual rice cultivars. The plot size was 3x4 m, with 15x20 (=300) rice hills per plot (Figure 2).

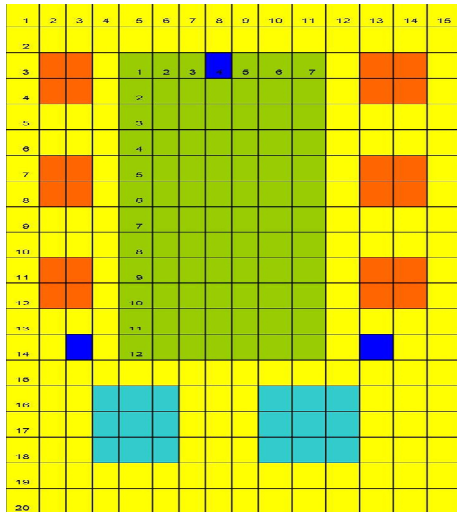

Figure 2: Plot design, green part: harvest area, orange part: sample taking area, light blue: area for lysimeters, yellow part: border area, dark blue: phyllochron

A ten meter gap was left between the blocks to avoid water flux between the treatment systems (Figure 3).

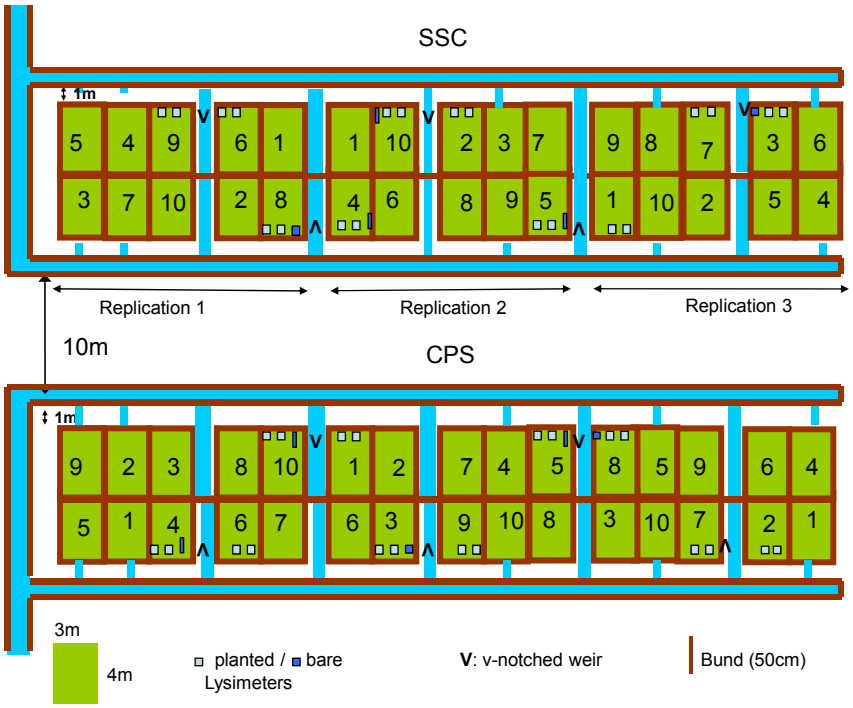

Figure 3: Experimental layout with 2 irrigation treatments (CPS=Conventional Paddy System, SSC=System of Saturated Conditions) (Source: Sabine Stürz)

Each experimental plot was enclosed by bunds of 30 cm height and reinforced by PVC[1] foil to minimize lateral seepage between plots. In preparation of the experiment the field was ploughed and flooded. Seeds were direct seeded after pre-soaking for one day, then incubating them into the soil for two more days. All plots were sown on July 10, 2008. Only Sahel 202 was sown with one week delay on July, 17 2008, due to germination problems of the designated cultivar ITA 212. For each hill three germinated seeds were put into a hole and covered with sand. At 19 DAS the smallest of the three rice plants was removed. 120 kg N ha^{-1} (Urea), 60 kg P ha^{-1} (Di-ammonium-phosphate, 18-46) and 60 kg K ha^{-1} (KCl) were applied as fertiliser. N was applied at three different growth stages (split application 40/40/20) - 21 DAS, PI and booting stage, respectively. P and K were applied with the first application of N. There was a constant water layer of about 5 cm until three weeks after sowing in both treatments to assure an optimal field establishment.

The herbicides Weedone[2] (Nufarm 2008) and Propanil[3] (Wood 2009) (1:4) were applied in addition to manual weeding. Pesticides (Furadan[4] (Kwizda 2008), Decis[5] (Bayer 2009)) were applied on a regular basis to assure optimal growing conditions.

4.3 Irrigation treatments and water loss measurements

There were two irrigation regimes, one block was irrigated as a conventional paddy rice field with the soil being completely flooded during the cropping period, the other block was maintained in the system of Saturated Soil Conditions (SSC) where the soil was kept saturated and ponded water in the plots was avoided.

Irrigation was done via a V-notch weir to measure the volume of water influx into a plot. As shown in Figure 3 and Picture 1, two plots were supplied by one V-notch weir, there

[1] PVC=polyvinyl chloride

[2] Weedone® 638 (2,4-D Acid)

[3] Propanil (3,4-dichioropropionaniine)

[4] Furadan® granulated (Carbofuran 50g/kg)

[5] Decis® (Deltamethrin 25g/l)

being five weirs in each treatment of the experiment. Discharge trough a V-notch weir can be calculated from “Brater and King”-Equation adapted to the metric system (Appendix 1).

Equation 1: Theoretical discharge through V-notch weir

$$Q = 13.8 \tan(\theta/2) H^{2.5}$$

Where

- Q = Theoretical discharge (cm^3 sec^{-1})
- θ = Angle of V-notch weir (degrees)
- H = Head on apex of notch (cm) = $\alpha \cos(\theta/2)$ (cm)
- 13.8 = Theoretical constant before calibration ($cm^{0.5}$ sec^{-1})

Plots without a V-notch were watered by opening and closing the bunds.

The CPS was on average irrigated every three to four days and the flooded conditions were maintained throughout the vegetation period until two weeks before harvest. The SSC-treatment was irrigated at a higher frequency as water was applied in lower amounts.

Picture 1: V-notch weir between 2 plots, equipped with lysimeters

4.3.1 Conventional Paddy System

Water loss (Evaporation (E), Transpiration (T), and Percolation (P)) was estimated using lysimeters in the plots. The lysimeters were made from metal, squared and 60 cm sized in length and height, and were installed at a depth of 35 cm below ground. Four different types of lysimeters were used (Table 2).

Table 2: Description of lysimeters used in the experiment

Type A	Type B	Type C	Type D
- Planted with rice - Open on the bottom and on top	- Planted with rice - Closed on the bottom, open on top	- Not planted with rice - Closed on the bottom and with a lid	- Not planted with rice - Sized: 80x20x30 cm (length, width, height)
Estimation of E, T, P	Estimation of E, T	Estimation of P	Estimation of E between 2 rows

A type A- and type B-lysimeter were installed in each plot irrigated via a V-notch weir; additionally either a Type C- or D-lysimeter was installed in some of the plots. In contrast to the other lysimeters, type D was installed at a depth of only 5 cm below ground. Lysimeters were installed in ten plots in each block, ensuring that one plot of each variety was equipped with lysimeters. All lysimeters were equipped with rulers inside to measure water height, allowing the calculation of E, T and P.

Type A-lysimeters allowed the calculation of Evapotranspiration (ET), which is the sum of evaporation and transpiration (E+T=ET), of the soil and the rice plants, and also P in lower soil levels. Because of the closed bottom of type B only ET was measured, whereas with the type C model only P was measured. Type D was installed between two rows of rice to calculate soil evaporation. Therefore it had a different size compared to the other types (Table 2).

The water level in the lysimeters was measured before and after irrigation, and was adjusted to the same level as in the surrounding plot after irrigation.

In addition a graded wooden stick was installed in each plot to measure the water level before and after irrigation.

Picture 2: Different lysimeters (from left to right: Type C, A, and B)

Picture 3: Different lysimeters (from left to right: Type A, B, and D)

4.3.2 System of Saturated Soil Conditions

As the system had no ponded water layer, water loss was estimated by measuring soil water content using Time Domain Reflectometry (TDR, Umweltanalytische Produkte GmbH) (Produkte 2009; UP 2009). To calculate water loss, the soil in each plot irrigated via a V-notch weir was measured with the TDR before and after irrigation.

4.4 Observations and Measurements

4.4.1 Weather

A meteorological station close to the experimental plots monitored the weather conditions during the experiment, measuring temperature [°C], solar radiation [W m^{-2}] and wind speed [m s^{-1}]. A rain gauge was installed next to the field to measure precipitation [mm].

4.4.2 Water treatments

The water level in the lysimeters and the plots was measured in the CPS before and after irrigation. Additionally, the water level of the CPS and SSC was measured after a rain event. The TDR was used to detect water losses in the SSC.

4.4.3 Phenology

For each genotype the sequence of phenological stages and of leaf appearance were observed. “Leaf-appearance” was defined as appearance of the ligula. As the ligula appeared the leaf was marked using a white marker pen.

The following development stages were recorded: emergence, start of tillering, panicle initiation, booting, heading (at 50% and 100% of plants in the plot), flowering (at 50% and 100%) and maturity. Maturity was reached firstly if one panicle changed its colour 3/4 from green to yellow, and secondly when these conditions could be observed in the whole plot.

4.4.4 Sampling

Samplings were conducted in 21 day intervals on 4 neighbouring hills per plot.

Plant height, canopy height, and tiller numbers were recorded whereas plant height was measured with a ruler, and canopy height was measured with a gridded board.

From each hill the youngest fully developed leaf was sampled separately, the remaining hill was cut closely to the soil surface and roots were sampled using a squared metal root box (side length: 20 cm; depth 30 cm). After sampling the entire soil volume including the roots, roots were washed out closely to the plot using sieves, irrigation water and large bowls.

The aboveground biomass of the four hills was separated into leaves, stems, dead leaves, and later in the season also panicle. Samples were dried to consistent weight in an oven (75°C) and afterwards their weight was determined.

At maturity the harvest area (1,40 m x 2,40 m, 84 hills) of the plots was sampled. Panicles were removed after cutting down the harvest area. Tillers were counted, panicles were threshed, grains separated into filled and unfilled ones, and weighed. Additionally, the 100 grain weight of filled and unfilled grains was determined. Also the dry weight (DW) of the straw was measured. Grain weight was corrected to 14% moisture content, after determining the grain moisture content using a grain moisture meter.

4.4.5 Data processing and problems during cropping period

Data processing

Standardised Phenology

The progress in time along the phenological stages was converted into a standard development scale (standard index). Summerfield et al. (1992) converted the time from sowing to flowering by using the rate of progress towards flowering, i.e. the reciprocal of time taken from sowing to flowering, 1/*f*.

According to that 50% flowering was set to phenological stage 1 and all the stages in between were calculated for each genotype using the following equation.

Equation 2: Standardised Phenology

$$Standardised\ Phenology = \frac{1}{Number\ of\ Days\ until\ Flowering} \times Days\ to\ specific\ phenological\ stage$$

Non-linear extrapolation for biomass development to development stage

In order to harmonize the sampling frequency of 21 days intervals with the phenological development of the individual varieties a non-linear extrapolation of biomass accumulation was based on observed development stages. This allows comparing varieties at similar physiological stages. Curves for the development of aboveground dry matter until harvest and its derivate growth rate [g hill^{-1} day^{-1}] were fitted. The chosen equation for development of aboveground dry matter was:

Equation 3: Development of aboveground dry matter

$$lny = a + bx + cx^2$$

Problems during cropping period

To implement a similar irrigation in all the plots there have been problems such as heterogenic field preparation which resulted into different water holding capacities in the plots. Some of the plots have not been well puddled.

4.5 Statistics

The experiment was arranged as a split-plot-design, where the two irrigation treatments were separated into two blocks to facilitate irrigation.

Data were statistically processed with SAS (Proc glm) as a randomized block design to investigate possible statistical differences between the irrigation treatments and the genotypic responses.

Students T-test ($p \leq 0.05$) was applied to test the effect of the different irrigation treatments for the specific genotypes.

5 Results

5.1 Water use

Only the water inflow via V-notch weirs was used as indicator for water use in this thesis. The TDR-measurements were not yet established and due to the non-existent water layer in the SSC-treatment, lysimeters were of no use. Therefore, data for percolation, transpiration and evaporation in the SSC were not available, thus no comparison between CPS and SSC with regard to sources and orders of magnitude of water loss will be attempted.

Water savings [%] were calculated by the following equation:

Equation 4: Water savings [%]

$$Water\ savings[\%] = \frac{Water\ input\ \ CPS\text{-}system\ \ [mm] - Water\ input\ SSC\text{-}system\ [mm]}{Water\ input\ CPS\text{-}system\ [mm]} \times 100$$

Water input comprises irrigation and precipitation.

In the SSC on average 24% (200 mm) less water was applied compared to the CPS, whereas on average the similar yield was achieved in the two irrigation treatments (Figure 4).

The calculated water productivity [g grain m^{-2} mm^{-1}] was about 0.63 and 0.85 g grain m^{-2} mm^{-1} for the CPS and SSC (Table 3).

Table 3: Average water input (irrigation and precipitation) [mm], average yield [g grain m^{-2}] and calculated water productivity [g grain m^{-2} mm^{-1}]

Irrigation System	Water use (rainfall + irrigation) [mm]	Yield [g grain m^{-2}]	Water Productivity [g grain m^{-2} mm^{-1}]
CPS	820	517	0.63
SSC	626	530	0.85

Tested genotypes responded differently to the treatments, on the one hand there was a group of varieties (Sahel 108, IR 31785, WAS 6322) which used about the same amount of water for a similar yield in both treatments. On the other hand varieties such as WAS 161, Jaya, IR 64, Sahel 202 used up to 58% less irrigation water in the SSC without any penalty on yield (Figure 5). The varieties Chomrong and CG 14 were excluded from this analysis. This was due to extreme yield losses caused by birds.

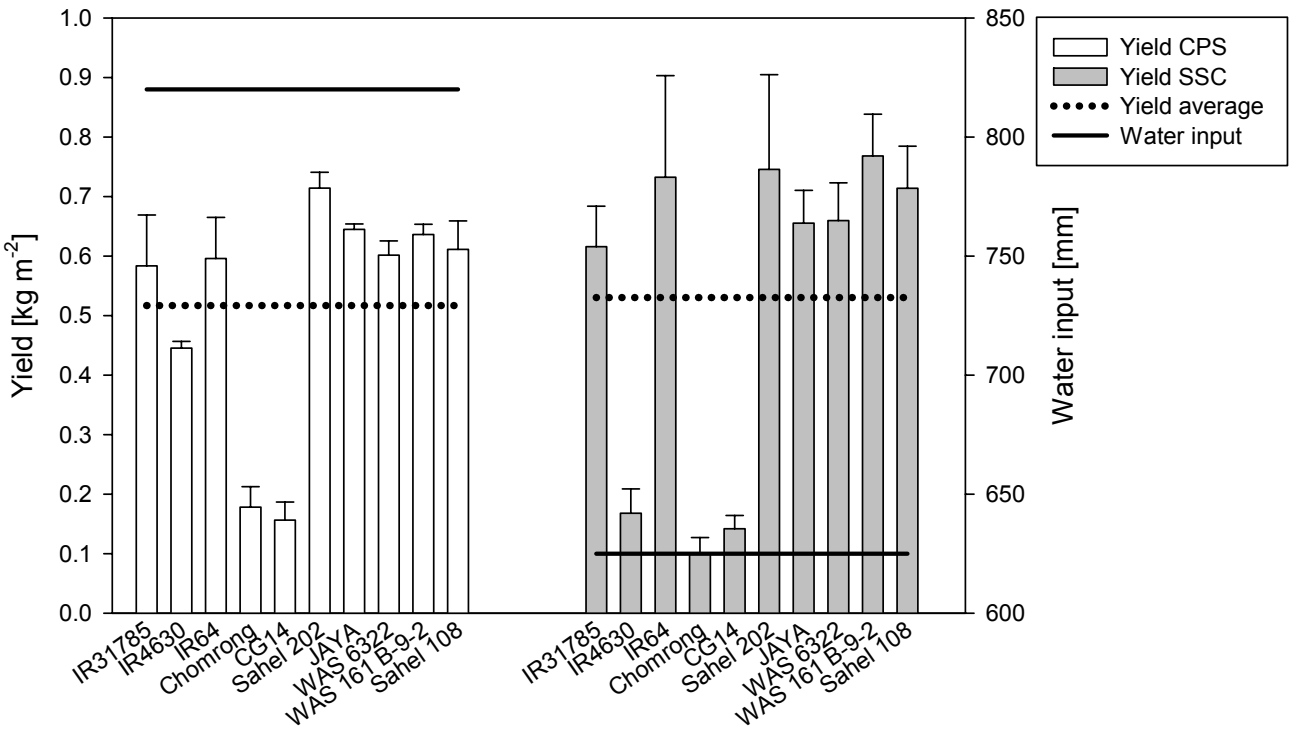

Figure 4: Yield comparison [kg m^{-2}] of the varieties between Conventional Paddy System (CPS) and system of Saturated Soil Conditions (SSC) with average of yield and water input [mm] (irrigation and precipitation); Standard error over repetitions of each variety

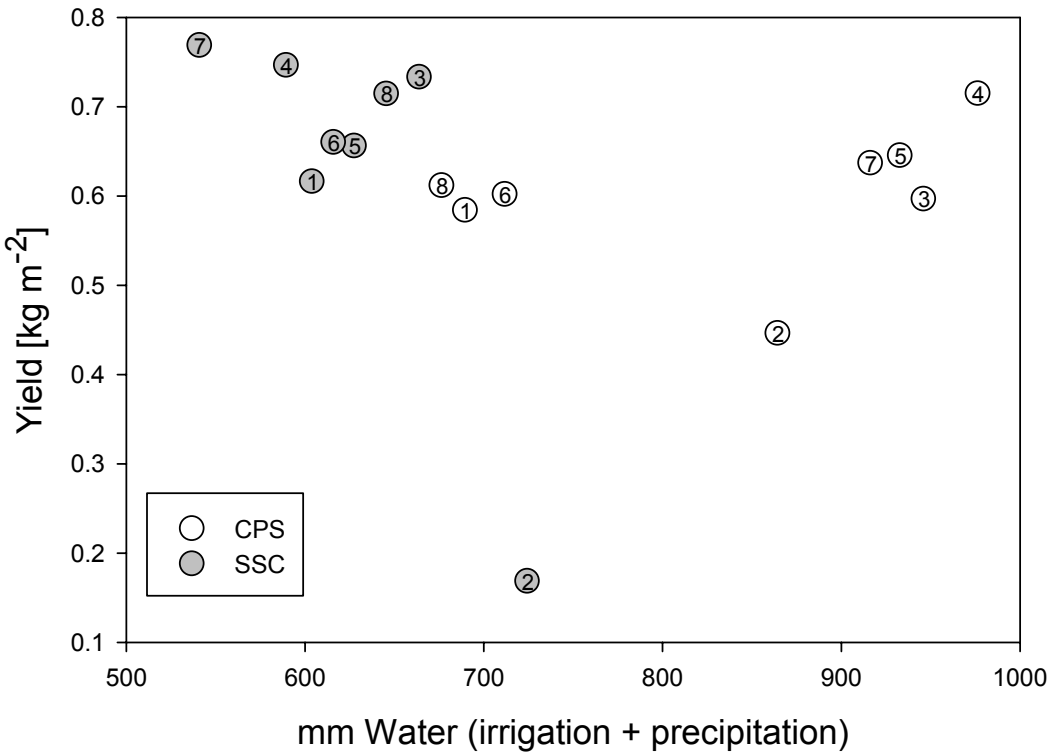

Figure 5: Yield [kg m^{-2}] over water input [mm] (irrigation and precipitation) for variety 1-8 in the Conventional Paddy System (CPS) and System of Saturated Soil Conditions (SSC); Variety-number: 1=IR 31785, 2=IR 4630, 3=IR 64, 4=Sahel 202, 5=Jaya, 6=WAS 6322, 7=WAS 161, 8=Sahel 108

Table 4: Water input [mm day^{-1}, irrigation and precipitation] for the varieties in the irrigation treatments (CPS, SSC), water savings [%] in the SSC compared to the CPS

	Water input [mm day^{-1}, irrigation + precipitation]		
Variety	CPS	SSC	water savings in SSC [%]
CG 14	8.0	7.4	0.07
Chomrong	10.7	7.9	0.26
IR 31785	8.1	6.7	0.17
IR 4630	7.9	6.6	0.17
IR 64	10.3	7.2	0.30
Jaya	9.2	6.2	0.33
Sahel 108	7.3	6.9	0.05
Sahel 202	8.7	5.1	0.41
WAS 161	9.9	5.9	0.40
WAS 6322	8.5	7.2	0.15

As shown in table 4 varieties such as CG 14 and Sahel 108 used about the same amount of water [mm day^{-1}] in the two irrigation treatments, whereas WAS 6322, IR 31785 and IR 4630 had 10-20% less water use [mm day^{-1}]. Some of the varieties had over 20% less water use - Sahel 202 (41%), Was 161 (40%), Jaya (33%), IR 64 (30%), and Chomrong (23%), respectively (Table 4).

IR 31785, IR 64, Sahel 108 and WAS 161 have been studied in detail for their water use. For IR 64 and WAS 161 the amount of water input via irrigation differed widely among the two irrigation systems compared to the cultivars Sahel 108 and IR 31785. The daily water input from irrigation [mm] during the specific cropping periods varied between 4.9 mm (IR 31785) and 7.3 mm (IR 64) in the CPS and 2.9 mm (WAS 161) and 4.2 mm (IR 64) in SSC (Figure 6a-d). The biomass accumulation in the two irrigation-systems did not differ for Sahel 108 and IR 64 (Figure 6b,c). IR 64 accumulated the same biomass in the SSC with 42% less of water, whereas for IR 31785 water savings in the SSC only amounted to approx. 7% (Figure 6a). The highest water savings were achieved with the cultivar WAS 161, which used less than 58% of the irrigation water in the SSC compared to CPS with no losses of biomass accumulation at all. In contrast biomass accumulation in SSC outreached CPS after flowering (Figure 6d).

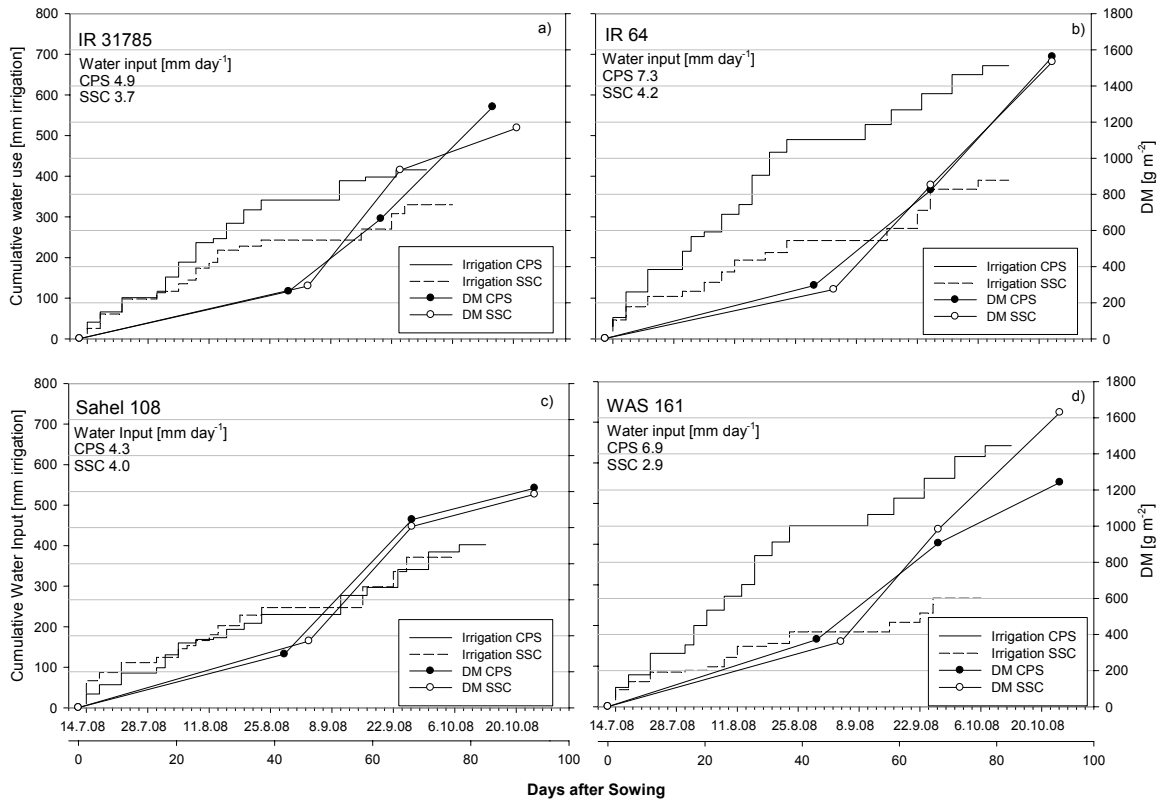

Figure 6a-d: Cumulative water input by irrigation [mm] via V-notch weirs over the cropping period in the rainy season 2008 for IR 31785, IR 64, Sahel 108 and WAS 191in the irrigation treatments Conventional Paddy System (CPS), Saturated Soil Conditions (SSC); precipitation during cropping period: 275.25 mm; biomass accumulation during cropping period in the two irrigation treatments of three phenological stages,1: Sowing to panicle initiation, 2: Panicle initiation to flowering and 3: Flowering to maturity.

With regard to biomass production versus water use (irrigation and precipitation) small differences were observed over the cropping period for e.g. Chomrong and IR 64 between the two irrigation-systems, for WAS 161 and CG 14 water productivity in the SSC was much higher than in the CPS. This is applicable to all three observed development stages (Table 5). In the development stage from sowing to PI the largest differences between water productivity in CPS and SSC were observed for WAS 161. From PI to flowering water productivity was much higher in the SSC as in the CPS for all varieties. From flowering to maturity water productivity was again higher in the SSC compared to the CPS e.g. for WAS 161. In total and averaged over all varieties water productivity increased by factor 1.6 from 0.90 g dry matter m^{-2} mm^{-1} in the CPS to 1.40 g dry matter m^{-2} mm^{-1} in the SSC.

Table 5: Ratio of water input [mm irrigation and precipitation] for the irrigation treatments Conventional Paddy System (CPS) and Saturated Soil Conditions (SSC); Water productivity: biomass production [g dry matter m^{-2}] over water input [mm irrigation and precipitation] for the specific phenological stages (Sow=Sowing, PI=Panicle Initiation, Flow=Flowering, Mat=Maturity)

		Water Productivity [g DM m^{-2} mm^{-1} Irrigation + Precipitation]							
	Index	Sow - PI		PI - Flow		Flow - Mat		Total	
Variety	SSC/CPS	CPS	SSC	CPS	SSC	CPS	SSC	CPS	SSC
CG 14	0.95	0.53	0.76	3.18	7.21	5.51	8.11	0.96	1.86
Chomrong	0.74	0.46	0.83	1.52	1.90	3.14	3.35	0.82	1.22
IR 31785	0.88	0.68	0.82	2.39	6.50	6.36	3.48	1.27	0.87
IR 4630	0.84	1.13	1.66	3.98	4.37	3.02	6.56	0.76	1.12
IR 64	0.70	0.63	0.80	1.96	5.11	5.51	5.01	1.11	1.48
Jaya	0.67	1.22	1.96	6.74	5.35	2.72	8.39	0.80	1.85
Sahel 108	0.95	1.14	1.04	3.27	6.24	2.49	2.90	0.69	0.85
WAS 161	0.59	0.42	1.26	2.51	5.56	2.01	6.83	0.58	1.85
WAS 6322	0.87	0.71	0.63	2.92	5.31	4.38	6.63	1.13	1.47
Av		0.77	1.08	3.16	5.29	3.91	5.69	0.90	1.40

5.2 Crop duration and phenological development

5.2.1 Crop duration

Crop duration (time until physiological maturity) as well the time between the phenological stages varied among the cultivars.

As Sahel 202 was sown one week later, the crop duration and phenological data of this variety were not statistically compared with the others.

In some varieties SSC prolonged crop duration as compared to the CPS, however, this difference was not statistically significant ($p \leq 0.05$). Chomrong had the shortest crop duration with an average of 76 days from sowing to phenological maturity. The longest duration was observed for IR 4630 with an average of 110 DAS (Table 6).

Table 6: Duration until maturity of the ten cultivars in the irrigation treatments: Conventional Paddy System (CPS) and Saturated Soil Conditions (SSC); Means sharing the same letter are not significantly different; $p \leq 0.05$; LSD=2.2; LD=long duration, MD=medium duration, SD=short duration

Variety	Crop duration [days]			Growth type
	Mean	CPS	SSC	
IR 4630	110[a]	109	110	LD
Jaya	102[b]	101	102	LD
Sahel 108	93[c]	93	93	MD
WAS 161	93[c]	93	92	MD
IR 64	92[c]	92	92	MD
IR 31785	88[d]	85	90	MD
CG 14	85[e]	84	86	SD
WAS 6322	85[e]	84	86	SD
Chomrong	76[f]	76	76	SD

The nine cultivars were arranged into three groups. In the first group varieties with short crop duration (≤ 85 days) can be found, the second comprises the ones with medium crop duration (85-95 days) and in the third group varieties with long crop duration (>95 days) can be found (Table 6).

On average onset of tillering was observed at 16.5 DAS (CPS 15, SSC 18) for all genotypes in both treatments, panicle initiation (PI) was reached around 49 DAS (CPS 47, SSC 51),

flowering at 67.5 DAS (CPS 67, SSC 68) and maturity was reached in the CPS around 91 DAS and in the SSC at about 92 DAS.

5.2.2 Phenological development

The duration from sowing to PI was significantly different between the CPS and SSC. In the SSC PI was observed on average at 51 DAS whereas itI was observed after 47 DAS in the CPS (LSD=0.58) (Figure 7a). All varieties, except for Jaya and IR 4630, had a significantly longer vegetative phase in the SSC (Students T-test, $p \leq 0.05$). Varieties differed significantly in the number of days from sowing to PI. Chomrong showed the shortest duration with an average of 41 and 45 days in the CPS and SSC, respectively. For IR 64 on average 43 and 47 days were observed, and the longest duration showed IR 4630 with an average of 62 and 64 days until PI in the CPS and SSC, respectively.

In both systems flowering of the different genotypes was observed at 67 DAS. The duration from PI to the stage of 50% flowering varied in both systems - in the CPS the average was 20 days and in the SSC 17 days. Hence, duration in the SSC was significantly shorter (LSD=1.1). According to the Students T-test ($p \leq 0.05$) duration from PI to flowering was significantly longer in the CPS than in SSC for the cultivars Chomrong, CG 14, Sahel 108, WAS 6322 and WAS 161. Additionally genotypic differences were observed: Chomrong showed the shortest period (13/10 DAS in the CPS/SSC, IR 4630 (21/19 DAS) and IR 64 (24/20 DAS) showed a medium duration and the longest span for reaching flowering was found for Sahel 108 (25/21 DAS) (Figure 7b).

The development stage from flowering to maturity was not significantly affected by the irrigation treatments for any given variety. Average duration was about 24 days from anthesis to maturity (LSD=0.48). Varieties differed in the deviation from flowering to maturity. For Chomrong a duration of 22/20 days from anthesis to maturity was observed in the CPS/SSC, for IR 64 24/25 days, and the longest duration from anthesis to phenological maturity was observed for IR 4630 with 26/27 days (LSD=1.03) (Figure 7c).

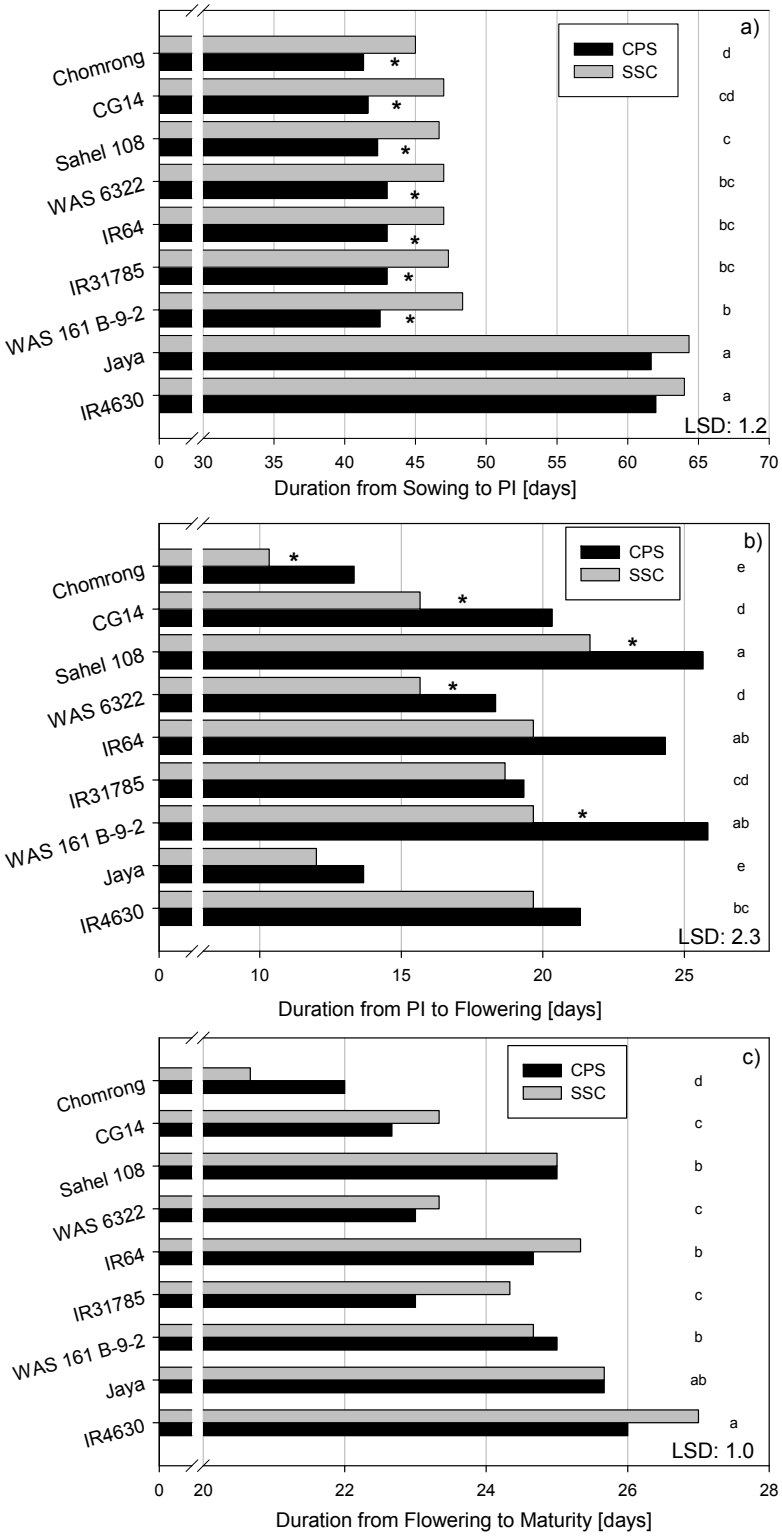

Figure 7a-c: Genotype specific duration [days] for development stages (Figure 7a: sowing to panicle initiation (PI), Figure 7b: PI to flowering, Fig. 7c: flowering to maturity) in 2 irrigation treatments (CPS and SSC), Means sharing the same letter are not significantly different, $p \leq 0.05$; * indicates treatment specific differences for a genotype (Students T-Test, $p \leq 0.05$).

Time requirements (in days) for reaching a certain development stage varied strongly between the different varieties. Different growth stages (e.g. yield formation) strongly depend on the phenological stage, because of this, phenological development was converted to a time-independent, genotype-specific scale. Mean PI in the SSC was on average 0.74 on a scale between 0 and 1 and, thus, significantly higher than in the CPS with an average of 0.70 (LSD=0.02) (Table 7). Jaya and Chomrong showed the highest value of standardised PI, Sahel 108 the lowest. The higher the value of the standardised PI the later the variety reached PI or the less time was between PI and flowering.

Table 7: Means of standardised PI,
Means sharing the same letter are not significantly different; $p \leq 0.05$; LSD=0.03

Variety	Mean
Jaya	0.83 [a]
Chomrong	0.79 [b]
IR 4630	0.76 [c]
WAS 6322	0.73 [d]
CG 14	0.71 [d]
IR 31785	0.70 [de]
WAS 161	0.68 [ef]
IR 64	0.67 [f]
Sahel 108	0.65 [f]

5.3 Development of aboveground dry matter and tiller number

5.3.1 Treatment specific comparison

In total four samplings were conducted for all varieties in the two irrigation treatments - 21 DAS, 41 DAS, 62 DAS and 84 DAS respectively.

Aboveground dry matter [g m^{-2}] and tiller number were recorded. On average irrigation treatments did not significantly affect biomass accumulation (Figure 8).

Tiller number across all varieties was significantly increased in the CPS 21 DAS, whereas with time tiller number increased in SSC resulting in significantly more tillers at the last two sampling dates (Figure 9).

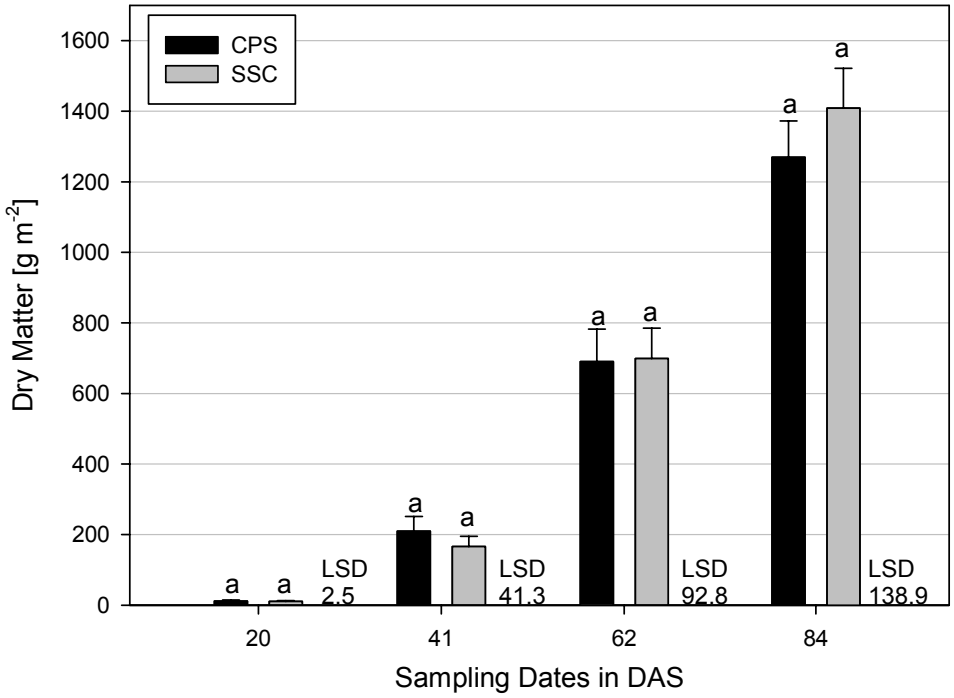

Figure 8: Development of aboveground dry matter [g m^{-2}] averaged across all varieties at each sampling date for the irrigation treatments Conventional Paddy System (CPS) and Saturated Soil Conditions (SSC); error bars=SE for treatments per sampling date across genotypes; means sharing the same letter are not significantly different for the specific sampling date; $p \leq 0.05$

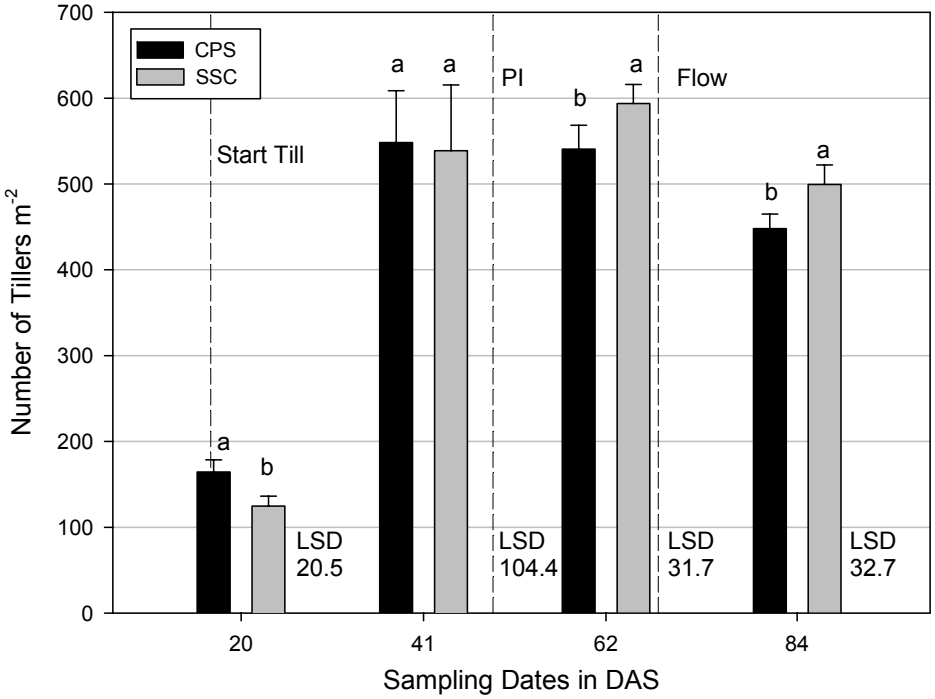

Figure 9: Number of tillers [m^{-2}] averaged across all varieties at each sampling date in the two irrigation treatments CPS and SSC; error bars=SE for treatments per sampling date across genotypes; means sharing the same letter are not significantly different at the specific sampling date; $p \leq 0.5$; vertical broken lines indicate average development stages: Till=onset of tillering; PI=panicle initiation; Flow=flowering

5.3.2 Comparison of genotypes

The effect of the irrigation treatments on the biomass production of individual genotypes was tested in an ANOVA. Genotype specific responses to the irrigation treatments were not significantly different for samplings done later than 21 DAS (Table 8). WAS 6322 had the highest aboveground biomass accumulation 21 DAS with 15.6 g m^{-2}, whereas CG 14 accumulated the least dry matter with 3.8 g m^{-2}. At all the other sampling dates cultivars did statistically not differ in regard to biomass accumulation.

Table 8: Dry matter (DM) [g m^{-2}] for each sampling date; sampling was done each 21 days, means sharing the same letter are not significantly different; p≤0.05;
* was not included in statistical observations
dates; + harvested already

Variety	Biomass [g m^{-2}]			
	21 DAS	41 DAS	62 DAS	84 DAS
CG 14	3.8 ^{d}	178.7 ^{a}	850.6 ^{a}	1529.5 ^{a}
Chomrong	12.6 ^{abc}	183.3 ^{a}	707.8 ^{a}	+
IR 31785	9.9^{bc}	209.5 ^{a}	712.0 ^{a}	1275.4 ^{a}
IR 4630	11.3 ^{abc}	169.3 ^{a}	641.0 ^{a}	1308.2 ^{a}
IR 64	9.00 ^{c}	227.3 ^{a}	675.1 ^{a}	1373.8 ^{a}
Jaya	12.5 ^{abc}	203.5 ^{a}	588.8 ^{a}	1359.6 ^{a}
Sahel 108	14.2 ^{ab}	199.0 ^{a}	860.6 ^{a}	1258.0 ^{a}
Sahel 202	*	*	541.7 ^{a}	1091.2 ^{a}
WAS 161	14.5 ^{ab}	194.3 ^{a}	713.9 ^{a}	1394.9 ^{a}
WAS 6322	15.6 ^{a}	184.9 ^{a}	680.2 ^{a}	1326.3 ^{a}
LSD	5.2	87.5	207.9	294.6

Tiller number of the varieties differed significantly in the cropping season except at the second sampling date (42 DAS) (Table 9). At the first sampling date Jaya had the highest tiller number with 187 tillers m^{-2}, whereas for CG 14 the lowest tiller number was observed (110 tillers m^{-2}). At the third sampling date CG 14 had the highest tiller number with 670 tillers m^{-2} and Chomrong the lowest with 444 tillers m^{-2}. At the fourth sampling date IR 64 had the highest tiller number with 521 tillers m^{-2} and CG 14 the lowest with 408 tillers m^{-2}. The fourth sampling was conducted after flowering stage, so that only reproductive tillers were counted explaining the apparent loss of tillers from the third to the fourth sampling. Especially the varieties CG 14, Sahel 108 and Jaya showed a strong decrease from 62 to 84 DAS. CG 14 had 262 tillers m^{-2} less (meaning 11 tillers less per hill), Sahel 108 156 (6 tillers less per hill) and Jaya 155 (6 tillers less per hill).

Table 9: Tiller number for each sampling date [Tillers m^{-2}], sampling was done each 21 days, means sharing the same letter are not significantly different, $p \leq 0.05$; * was not included in statistical observations; + harvested already

Variety	Number of tillers [m^{-2}]			
	21 DAS	41 DAS	62 DAS	84 DAS
CG 14	110 ^{d}	510 ^{a}	670 ^{a}	408 ^{c}
Chomrong	122 ^{cd}	356 ^{a}	444 ^{e}	+
IR 31785	130 ^{cd}	513 ^{a}	585 ^{bc}	521 ^{a}
IR 4630	162 ^{abc}	474 ^{a}	538 ^{cd}	485 ^{ab}
IR 64	168 ^{ab}	663 ^{a}	590 ^{bc}	521 ^{a}
Jaya	187 ^{a}	546 ^{a}	576 ^{bc}	420 ^{bc}
Sahel 108	171 ^{ab}	615 ^{a}	620 ^{ab}	465 ^{abc}
Sahel 202	*	*	477 ^{de}	426 ^{bc}
WAS 161	146 ^{abcd}	657 ^{a}	585 ^{bc}	496 ^{a}
WAS 6322	171 ^{ab}	593 ^{a}	585 ^{bc}	522 ^{a}
LSD	42.9	ns	70.8	69.4

At 21 DAS IR 64, Jaya and Sahel 108 had significantly more tillers m^{-2} in the CPS than in the SSC, after 62 DAS IR 46 and Jaya had more tillers in the SSC-treatment, and 84 DAS CG 14, IR 46, Jaya and Sahel 108 had more tillers m^{-2} in the SSC (Students T-test, $p \leq 0.05$). That means that in the prolonged vegetative stage (Figure 7a) to PI the varieties produced more tillers. A table which shows the specific tiller numbers for the irrigation treatments is shown in Appendix 3.

The following results will be presented for only three varieties representing typical genotypes for the groups of short-duration (Chomrong), medium-duration (IR 64) and long-duration (IR 4630) varieties.

Biomass accumulation in both treatments was plotted against phenological stage to compare the effects of irrigation treatments (Figure 10). SSC promoted biomass accumulation in IR 4630, but did not affect biomass accumulation for the two other varieties. For Chomrong the lowest aboveground dry matter was observed in this comparison.

At flowering stage the aboveground dry matter of the three varieties did not differ in the two irrigation systems. Aboveground dry matter was only slightly higher in the SSC. IR 64 showed a lower biomass accumulation at PI in the SSC but reaching flowering biomass production showed a stronger development in the SSC and at the flowering stage the biomass accumulation did not differ between the two irrigation-systems. Development, however, was slowed down in the short- and medium-duration varieties in the SSC until flowering, whereas the effect was not seen in the long-duration variety (Figure 10, Development stage: PI).

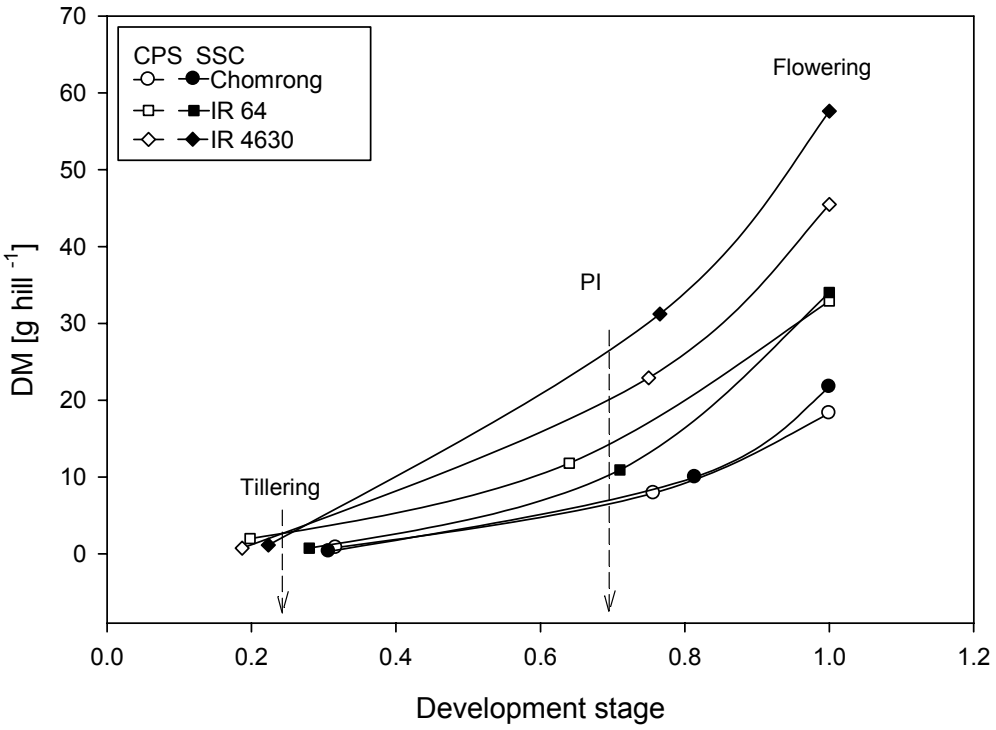

Figure 10: Aboveground dry matter (DM) [g hill^{-1}] of Chomrong (circle), IR 46230-22-20 (diamond) and IR 64 (square) plotted for development stage based on standardised scale (unfilled symbols=Conventional Paddy System (CPS); filled symbols=Saturated Soil Conditions (SSC); each phenological stage is represented with the particular symbol, PI=Panicle Initiation

Biomass accumulation was plotted against crop duration for observing growth rate and biomass development. The fitted curves are shown in the Figures 11a-f. When the short-duration variety Chomrong reached flowering stage, the long-duration variety IR 4630 just started PI. Short and medium-duration varieties had their peak in growth rate approx. at flowering stage, whereas for long-duration varieties the peak was observed at PI and during flowering stage the growth rate was already decreasing. For all varieties growth rate in SSC was higher than in the CPS, especially at or right after PI. The highest growth rate in the selected cultivars was approx. 0.1/1.5 g DM hill^{-1} day^{-1}in the CPS/SSC for Chomrong (Figure 11a,b), 1.2/1.4 g DM hill^{-1} day^{-1} for IR 64 (Figure 11c,d) and 1.1/1.4 g DM hill^{-1} day^{-1} for IR 4630 (Figure 11e,f). For Chomrong and IR 64 a small depression between 20-40 DAS could be observed. The longer the crop duration the more negative was the growth rate in the end.

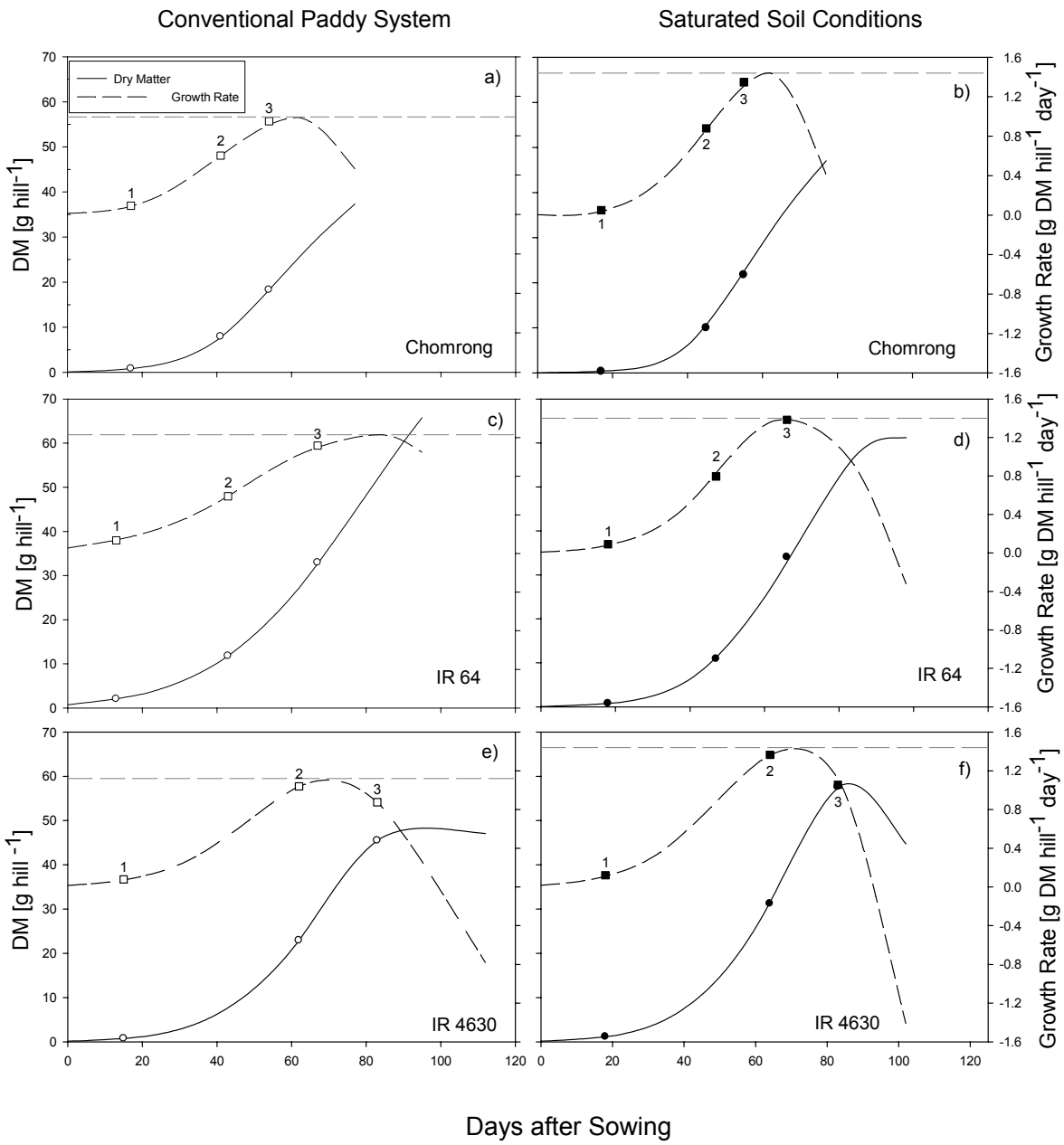

Figure 11a-f: Development of aboveground dry matter [DM g hill^{-1}] and Crop Growth Rate (derivate from DM) [g DM day $^{-1}$ hill $^{-1}$] over the cropping period for the varieties Chomrong (a+b), IR 64 (c+d), IR 4630 (e+f), in the two irrigation-treatments (empty circle =Conventional Paddy System, filled circle=Saturated Soil Conditions); Number 1-3 indicate phenological stages (1=Start Tillering, 2=Panicle Initiation, 3=Flowering)

5.4 Yield components

In some plots bird damage could not be prevented, resulting in yield loss. This damage amounted to 75% in Chomrong and CG 14 in all replications and to 25% in one replication of IR 31785, IR 64 and three replications of Sahel 108.

Yield was not affected by the two irrigation treatments (Table 10). The average yield of the varieties was 0.52 kg m^{-2} (CPS: 0.51 kg m^{-2}, SSC 0.53 kg m^{-2}). Sahel 202 achieved with an average of 0.73 kg m^{-2} the highest yield and Chomrong with approx. 0.14 kg m^{-2} the lowest, partly due to bird damage. By plotting yield for each variety and treatment the decline in yield of IR 4630 in the SSC was obvious (Figure 4).

Table 10: Yield [kg m^{-2}], Harvest Index and Sterility [%] for all varieties, varieties are listed according to highest yield; means with the same letter are not statistically different, $p \leq 0.05$

Variety	Yield [kg m^{-2}]			Harvest Index [%]	Sterility [%]
	Average	CPS	SSC		
Sahel 202	0.73 ^{a}	0.71	0.75	0.48 ^{abc}	37.1 ^{bc}
WAS 161	0.70 ^{a}	0.63	0.77	0.49 ^{abc}	25.6 ^{c}
IR 64	0.66 ^{a}	0.59	0.73	0.44 ^{bcd}	36.2 ^{bc}
Sahel 108	0.66 ^{a}	0.61	0.71	0.53 ^{ab}	37.5 ^{bc}
Jaya	0.64 ^{a}	0.62	0.66	0.54 ^{ab}	38.4 ^{bc}
WAS 6322	0.63 ^{a}	0.60	0.66	0.58 ^{a}	37.4 ^{bc}
IR 31785	0.60 ^{a}	0.58	0.62	0.52 ^{ab}	46.6 ^{b}
IR 4630	0.28 ^{b}	0.44	0.16	0.33 ^{de}	44.3 ^{b}
CG 14	0.15 ^{bc}	0.16	0.14	0.31 ^{e}	68.2 ^{a}
Chomrong	0.14 ^{c}	0.17	0.10	0.37 ^{cde}	45.7 ^{b}
LSD	0.14			0.06	8.21

Excluding Chomrong and CG 14 average yield increased to 0.63 kg m^{-2} in the SSC and to 0.60 kg m^{-2} in the CPS. Cultivars which had higher yields in the SSC were for example Sahel 108 (CPS: 0.61 kg m^{-2}, SSC: 0.71 kg m^{-2}), WAS 161 (CPS: 0.63 kg m^{-2}, SSC: 0.76 kg m^{-2}), and IR 64 (CPS: 0.59 kg m^{-2}, SSC: 0.73 kg m^{-2}). Chomrong and IR 4630 achieved higher yields in the CPS. Chomrong achieved 0.18 kg m^{-2} in the CPS and 0.10 kg m^{-2} in SSC and IR 4630

0.44 kg m^{-2} in the CPS and 0.17 kg m^{-2} in SSC. According to Students T-test ($p \leq 0.05$) IR 4630 had significantly different yields in the two different irrigation-systems.

Field yield is the sum of several yield components such as panicle number*m^{-2}, number of grains in a panicle, number of unfilled grains in a panicle (sterility) and 1000 grain weight (TGW) as an indicator for grain filling. In the following only sterility will be exemplarily shown.

Sterility was calculated by the following equation:

Equation 5: Sterility [%]

$$Sterility\ [\%] = \frac{Number\ of\ empty\ grains}{Number\ of\ total\ grains} * 100$$

There was no statistical difference in overall sterility between the irrigation treatments; with an average sterility of 41% in both treatments. CG 14 showed significantly the highest sterility with 62%, followed by IR 31785 (47%), Chomrong (46%), and IR 4630 (44%). The lowest sterility was found for WAS 161 with about 26% (Table 10).

Even though the two irrigation treatments had no effect on sterility averaged across genotypes there have been differences for particular varieties. IR 46 and Chomrong showed a higher sterility in SSC than in CPS. IR 46's sterility for example was 32% in the CPS compared to 56% in the SSC, which was according to Students T-test ($p \leq 0.05$) significant. Other cultivars such as IR 31785, Sahel 202 and WAS 161 had a lower sterility in SSC, e.g. Sahel 202 had 42% of sterility in the CPS compared to 32% in SSC. For WAS 161 and Sahel 202 the increase of sterility in the CPS was significant (Students T-test, $p \leq 0.05$).

The Harvest Index (HI) was calculated by the following equation:

Equation 6: Harvest Index

$$Harvest\ Index = \frac{Weight\ of\ grains\ (14\ \%)[g]}{Aboveground\ dry\ mass\ [g]}$$

The two irrigation treatments did not significantly affect HI, the average mean in the CPS was 0.48, and in the SSC 0.44, respectively. The significantly highest HI was found for WAS

6322 with about 0.58. The lowest indexes were measured for IR 4630, CG 14 and Chomrong (Table 10).

As already for yield and sterility there were also for HI genotypic differences in relation to the different irrigation treatments. IR 46, Chomrong, IR 64, Sahel 108 and WAS 6322 had a lower HI in SSC compared to the CPS, e.g. HI of Chomrong was about 0.48 in the CPS and 0.27 in SSC, respectively, which was significant according to the Students T-test ($p \leq 0.05$). IR 31785 had a higher HI in SSC (0.57) compared to the CPS (0.46). WAS 161 and Sahel 202 had about the same HI in the two irrigation treatments (Sahel 202: 0.48, WAS 161: 0.49).

6 Discussion

Agriculture will be confronted with water scarcity in future due to less and irregular precipitation because of changing climate on the one site and the decreasing availability of water through pollution and resource depletion on the other site. Therefore it is important to implement water saving production methods and techniques in agriculture in general, and in rice production in particular. For this reason the RISOCAS project was implemented. This project aims for testing the water saving method SSC under Sub-Saharan conditions and finding cultivars which are most suitable for these conditions. Therefore, cultivars from a broad genetic background were selected to be cultivated in a two years experiment. Cultivars were planted in bi-monthly staggered dates to study the genotypic response to reduced water availability relative to climatic parameters. Data used for this thesis cover only one rainy season; so the data's validity is limited and the focus will be only on particular cultivars. For water use it was not possible to do statistical analyses for genotypic differences because only ten plots per treatment were set-up with a V-notch weir, each plot represented one variety.

The major target of this thesis was to pre-select promising genotypic characteristics and cultivars for the SSC, hence, cultivars that can manage a reduced water input and still achieve reasonable yields.

6.1 Water Use

In the SSC 24% less water was used as compared to the CPS without a penalty to yield. In the CPS on average 820 mm, in the SSC 626 mm water (precipitation and irrigation) were applied to the plots. Water consumption for a rice cropping period can vary between 400-3200 mm (Yoshida 1981; Bouman et al. 2001). The soil properties are major determinants for water fluctuation by percolation and seepage; a high clay fraction can be associated with a good water holding capacity. The soil of the experimental site was a vertisol with a clay content of 47%. Water input was rather low as rice plants were probably able to satisfy their water requirements from the groundwater (shallow water table at 50 cm).

Tabbal et al. (2002) observed that irrigation requirements were reduced due to shallow water tables, potentially saving water. The good water holding capacity of the soil and the shallow water table probably lead to a low percolation rate in this experiment. Borrell et al. (1997) stated that differences in irrigation treatments result from variations in evaporation, seepage and percolation losses, whereas percolation rates increase with increasing depth of ponded water. For the SSC-treatment it can be assumed that less percolation occurred because of a lower hydraulic head due to the inexistent non-ponded water (Borrell et al. 1997). In systems with non-ponded water layers soil-cracking is likely to occur depending on soil properties (Lu et al. 2000). Thus, a high clay fraction in soil leads to swelling and shrinking and, therefore, cracking occurs. Hence, to conserve water soil cracking should be avoided. In the SSC-treatment just small cracks on the soil surface could be observed, which were not deep, so that water loss because of these cracks was negligible.

Genotypic differences in water consumption for the two irrigation treatments were observed. In the CPS WAS 6322, IR 31785, Sahel 108 consumed approx. 700 mm within the cropping period, this was less than the other varieties, which consumed ≥ 900 mm. One reason could be that WAS 6322, IR 31785 and Sahel 108 are short to medium duration varieties, so that the water savings could be explained by their shorter cropping period. But since the calculated water use [mm day^{-1}] showed a lower water input for these varieties, genotypic variance could be also a reason. Such contrasting water inputs among the varieties were not observed in the SSC. As already explained a reason for this may be less water input in general and due to the inexistent ponded water layer less percolation and seepage occurred in the SSC.

A 35% increased water productivity for grain yield was achieved in the SSC with 0.85 g grain mm^{-1} day^{-1} compared to 0.63 in the CPS without a yield loss. Similar results were obtained by Bouman et al. (2005), who showed that water input for SSC-treatments decreased on average around 23% with a non-significant yield reduction of 6%. Also Tabbal et al. (2002) found in SSC-treatments a yield reduction of 5% with water input reductions of 35%, leading to 45% increase of water productivity. Bouman et al. (2005) stated that a high productivity results either from a high yield, or less water use or loss.

Because of a low water use in this experiment the water productivity was rather high particularly in the SSC. Bouman et al. (2005) conducted a closed-pot experiment where water inputs varied between 300-750 mm. As no seepage and percolation, thus hardly any water losses occurred, high water productivity was achieved.

Summarized, varieties such as WAS 161, Jaya, IR 64 and Sahel 202 showed water saving characteristics in the SSC, whereas Sahel 108, IR 31785 and CG 14 did not. The highest potential in saving water had WAS 161 and Sahel 202, Sahel 202 was characterized by the lowest daily water use at all. Additionally WAS 161, Sahel 202 and Jaya had good water productivity characteristics.

Due to the absent ponded water layer in the SSC the weed population increased compared to CPS (data not quantified). Borrell et al. (1997) described a negative correlation of water input and weed population - more weeds were found in the SSC than in the CPS for a wet season crop, similar results observed De Datta (1981). For future experiments it would be advisable to determine weed dry matter in the two irrigation systems, and to estimate the effect of a larger weed population on rice production in SSC.

Climatic conditions made it difficult to interpret the data of the two irrigation systems. Between 46 and 69 DAS 150 mm of precipitation occurred and during this time PI (49 DAS) and flowering (67 DAS) took place. It was quite hard to maintain effective SSC, thus standing water could not be avoided during this period in the SSC-treatment.

According to Bouman et al. (2007) the practical implementation of a SSC is difficult. Although conceptually sound, it is quite demanding to establish SSC as it requires frequent (eventually daily) applications of water to keep the soil saturated.

6.2 Crop duration and phenological stages

Total crop duration was not significantly affected by the irrigation treatments, whereas the duration of individual phenological stages was. Crop duration of the different varieties and treatments varied between 76-110 DAS. There were genotype-specific differences. Chomrong had the shortest crop duration (76 days), and IR 4630 the longest (110 days) (Table 1). Crop duration strongly depends on the duration of the vegetative phase until

flowering. Dingkuhn et al. (1995) stated that flowering occurs when a genotype-specific number of heat-units (T_{sum}) are accumulated, explaining the genotypic differences in the experiment. The vegetative phase is subdivided in a basic vegetative phase (BVP), a photoperiod sensitive phase and a post-photoperiod sensitive phase (Roberts 1987).

In general crop duration was rather short. Possible reasons may have been direct seeding and favourable weather conditions during the rainy season. The aim of the experiment was to evaluate genotypic responses to SSC and not to implement drought stress. SSC are prone to drought stress, which in turn is known to increase crop duration (Bouman et al. 2005). In this experiment crop duration was not affected by the SSC. WARDA classifies varieties with regard to crop duration as short-duration (<120 days), medium-duration (≥120 days) and long-duration (>140 days) varieties in transplanted rice (Dingkuhn et al. 1995). Since in this experiment the variety with the longest crop duration (IR 4630, 110 days) would have been classified as a short-duration variety, a different classification system for crop duration was adopted (Table 6). In general crop duration for the cultivars IR 64, IR 4630, IR 31785, Sahel 202, Jaya and CG 14 was in the range of crop duration already mentioned in literature for West-Africa (Dingkuhn et al. 1995; Craufurd et al. 2003).

In contrast to this, the comparison made between the actual growth duration and the one predicted with the Rice-Development (RIDEV) model showed a different result. The model was developed and validated for Sahel regions by Dingkuhn et al. (1995). The model estimates crop growth and can therefore be used to estimate optimal sowing date, optimal timing of fertilisation, and timing of harvest. Crop duration in this experiment was in general shorter compared to data calculated with RIDEV. According to RIDEV (using weather data from 2008) Jaya would have reached maturity at 119 DAS, compared to 102 DAS observed in this experiment. The same is valid for IR 64 (RIDEV 100 DAS/experiment 92 DAS), IR 31785 (RIDEV 114 DAS/experiment on average 88) and IR 4630 (RIDEV 128/experiment 110), indicating that some basic assumptions in RIDEV may have been rendered invalid with the immanent climate changes.

In terms of phenological stages the varieties needed in the SSC 4 days longer to reach PI, whereas the stage from PI to flowering was 3 days shorter. On average flowering stage

was reached 67 DAS. Similar data were presented by Dingkuhn et al. (1995). In their experiments it took 40-60 days to reach anthesis, and also in experiments of Borrell et al. (1997) anthesis occurred 70 DAS. The duration from anthesis to maturity was 24 days in this experiment which is similar to 28 days observed by Dingkuhn et al. (1995).

In the SSC rice plants were exposed to less water input and non-ponded water conditions. Water deficit can delay all development stages (Heenan et al. 1984; Lilley et al. 1994; Boonjung et al. 1996). Borrell et al. (1997) found that water deficit treatments like SSC or II-systems increased the duration from sowing to PI up to 5 days, whereas it needed less time to reach the reproductive period starting with anthesis (up to 5 days) in the water deficit treatments, which is similar to the results of this experiment with 4 days longer until PI and 3 days less until flowering in the SSC compared to CPS. It could be possible that drought affected the development stage until PI for short- and medium duration varieties; this would be an explanation for the longer vegetative phase until PI in the SSC. But due to rainfall after 46 DAS, the resulting ponded water layer and the shallow water table in general, drought stress may not be the main factor explaining the different periods in the development stages. Other reasons for the longer phase until PI could be temperature stress, problems in nutrient availability (NH_4) or soil compaction.

Temperatures above the optimal range (23-26°C) can delay plant development and alter the cycle of the phenological stages. Micro-climatic conditions within and below the canopy must have differed between CPS and SSC as mean water temperatures are in general below air temperature under a closed canopy (Dingkuhn et al. 1995). On sunny days Dingkuhn et al. (1995) observed maximum water temperature 14°C lower than the maximum air temperature. So it could be possible, that temperature stress was higher in the SSC and influenced phenological development, which would be another explanation for the delayed phase until PI. Due to the rainfall after PI and the temporarily existing ponded water layer it is possible that the favourable growing conditions accelerated plant development explaining the shorter phase from PI to anthesis.

A ponded water layer serves as temperature buffer, i.e. temperature extremes of day and nights are compensated. A bare soil heats up fast, but also cools down at night. So most

likely rice plants in the SSC were much more exposed to these temperature extremes during the cropping period.

In regard to the relatively high and different values of standardised PI, the explanation may be genotypic variation. A possible reason for the higher values could be a short time span between PI and flowering. For instance, Jaya and IR 4630 (representing long duration varieties) had a long period until PI; they both reached PI 63 DAS. As Jaya had a shorter period until anthesis the standardised PI value for Jaya (0.83) is much higher compared to IR 4630 (0.75) which reached anthesis 84 DAS. Chomrong, as a short duration type, also had a higher standardised PI value due to a short period between PI (43 DAS) and anthesis (55 DAS). Sahel 108 had a PI value of 0.65, PI was reached on average 45 DAS and anthesis about 68 DAS. It can be concluded that a relative late PI or a short period between PI and flowering resulted in higher standardised PI values and can be explained by genotype specific variation. Lilley et al. (1994) observed 38 days from PI to flowering which is longer compared to the varieties in this experiment, which had a short period between PI and flowering. The variety with the longest duration for the period from PI to anthesis was Sahel 108 with 25 DAS in the CPS and 21 DAS in the SSC.

As the experiment was conducted during the rainy season, the main rice cropping period in Senegal, climatic constraints to crop development, such as low temperatures and unsuitable photoperiod conditions did not occur.

6.3 Development of aboveground dry matter and tiller number

There was no statistical difference in aboveground dry matter accumulation [g m^{-2}] between the two irrigation treatments at any sampling date, hence, the SSC-treatment did not negatively affect the accumulation of biomass. The non-significant lower biomass accumulation in the SSC at the start of the experiment may be explained by stress caused by removing the shallow water layer after the first three weeks of cultivation, in addition causing soil compaction which may then have affected the development of young roots and plants. For II-systems Heenan et al. (1984) found a significantly decreased biomass production and less tiller compared to permanent flooded conditions at PI.

Statistical differences between genotypes for aboveground dry matter only occurred on the first sampling (21 DAS). A reason therefore may be the genotype specific start of development. A high vegetative vigor, i.e. quick accumulation of biomass by achieving a high specific leaf area or many tillers, assures a good competitiveness against weeds (Dingkuhn et al. 1999). Therefore genotypes characterized by high growth vigor in the vegetative stage or a non-erected canopy properties could have advantages in SSC. WAS 161, Jaya, Sahel 108, WAS 6322 had a fast biomass accumulation at the first sampling 21 DAS.

In terms of tiller number m^{-2} statistical differences were observed across genotypes between the two irrigation treatments except for the second sampling date. 21 DAS there were more tillers in the CPS. At the third sampling date (62 DAS) more tiller were counted in the SSC, which could be explained by the delayed PI in SSC. Plants were able to develop more tillers in the SSC, especially the long-duration varieties. Precipitation events between 40-60 DAS should be considered, as more water was available in the SSC due to a shallow water layer, which could have accelerated crop development.

The strong decrease of tillers from the third (62 DAS) to the last sampling date (84 DAS) may be due to the fact that non-productive tillers were aborted.

Statistical differences in tiller numbers between the varieties can be related to genotypic characteristics. As already mentioned above a high tiller number can be positive for a better competitiveness and increases yield. But this is only the case when tillers develop into productive ones which is then a beneficial genotypic trait for SSC.

With regard to water productivity for biomass accumulation, on average the same amount or even more aboveground biomass was accumulated in the SSC. Because of the fact that none of the varieties showed a decreasing biomass accumulation in SSC, the CPS comprised a systematic water penalty. Water was lost either by transpiration, which was thereby not significantly productive, as there were no higher yields, tiller numbers or biomass accumulation in the CPS, or due to water losses such as evaporation from the water surface, percolation into deeper soil horizons, seepage and overbund-flow in the field. Borrell et al. (1997) reported higher water losses under flooded field conditions and suggested that evaporation, percolation and seepage losses were higher with ponded water.

The experimental site was characterized by a relative shallow water table and a soil with a share of 47% of clay, indicating a high water holding capacity, thus the main water loss could be due to seepage and overbund-flow into the area next to the field.

The fact that the Crop Growth Rate (CGR) was not negatively influenced in the SSC profound the above conclusion, since none of the varieties showed a lower CGR in the SSC. Only differences with regard to genotype specific crop duration were found. SSC promoted CGR for Chomrong and IR 4630, but this did not have an influence on yield for these varieties.

Summarized, it can be said that development in the SSC was not less than in the CPS. Especially after the flowering stage the development was the same or even better.

6.4 Yield, Harvest Index and Sterility

There was statistically no difference in yield (on average 0.52 kg m^{-2}) in the two irrigation-systems, so it can be stated that the SSC produced the same yield with less water. But in consideration of a shallow water table, it is difficult to state whether SSC were not detrimental to the crop or if there would be other results with a deeper water table. Nevertheless, under these field-conditions water could be saved through implementation of SSC.

Borrell et al. (1997) reported no yield difference between SSC and traditional flooded rice production and achieved 0.45 kg m^{-2} within a wet season crop. Similar results were obtained by Bouman et al. (2005). For an II-experiment Heenan et al. (1984) showed a reduction in grain yield compared to flooded conditions, which was related to reduced spikelets per panicle, percentage of filled spikelets and individual grain weight.

The panicles of the short-duration varieties Chomrong and CG 14 were strongly damaged by birds during the whole ripening stage, explaining the lower yield and the high sterility. Lodging occurred for CG 14 and Chomrong towards the end of the cropping period, which could be another reason for the lower yield.

The strong yield decrease of IR 4630 from 0.44 kg m^{-2} in the CPS to 0.16 kg m^{-2} in the SSC is striking, because it stands in contrast to the overall yield results among the cultivars. A

possible reason could be that IR 4630 could not manage the reduced amount of water applied in the SSC-treatment. An explanation for the high sterility and therefore low yield of IR 4630 could be high temperature around anthesis. During the reproductive stage high temperatures are more detrimental to rice than during the vegetative stage (Yoshida 1981). Flowering as part of the reproductive stage is most sensitive to high temperatures. Dingkuhn (1995) reported that, especially for IR 4630, a critical daytime temperature of 37°C results in 50% spikelet sterility and is detrimental especially between heading and milky stage. Daily mean temperatures were used instead of maximum temperatures as anthesis and pollination happen in the morning. In this experiment IR 4630 reached anthesis around 84 DAS. Maximum temperatures during this time were ≥ 35°C, daily mean temperature was 31°C. But as there was higher stress (e.g. higher temperatures, less water) in the SSC, heat induced sterility may be one factor explaining the higher sterility. Similar results regarding heat stress and, therefore, a higher sterility have been shown by Wassmann et al. (2009). Chomromg, CG 14 and IR 31785 also had a high sterility. For the increased sterility of CG 14 as an *Oryza glaberrima* no explanation was found, these specie is known to have anthesis early in the morning to escape heat stress, hence, to counteract possible sterility (Yoshida 1981).

The HI achieved in this experiment was on average 0.48 in the CPS and 0.44 in the SSC. This was similar to results shown by Borrell et al. (1997). They found a HI of 0.49 in conventional flooded systems and a HI of 0.48 in SSC. The HI indicates the remobilisation of carbohydrates out of plant material into the grain. So this would be also an important trait for selecting promising cultivars. WAS 6322 (0.58) had the highest HI followed by Sahel 108 (0.53) and Jaya (0.54).

6.5 Promising genotypes

With the observations made in this experiment the cultivars could be classified into genotypes with traits beneficial or not for SSC.

The following traits could be beneficial for SSC:

- An early, high specific leaf area, an early vigor in general, assuring a high competitiveness against weeds
- Low water use, high water productivity, high drought resistance, and low transpiration rate
- High HI, as indicator for a strong remobilisation, and a high yield in general

For SSC it is beneficial to crop a long-duration variety in the rainy season when enough water is available, whereas in the dry season a short-duration type could be more advantageous. A prolonged cropping period increases the capability to recover from early weed pressure. In this experiment the medium- or long-duration varieties performed better than the short-duration varieties strengthening the conclusions just made.

By comparing the cropped varieties in regard to the traits listed above WAS 161, IR 64, Jaya and Sahel 202 seemed to be promising (Appendix 11).

They all had very good water saving characteristics; saving at least 30% of water. Still they achieved good yields and had low sterility. All these varieties are medium or long crop durations-types. The most suitable and promising varieties are Sahel 202 and WAS 161. Sahel 202, a long duration type, achieved the highest yield (0.73 kg m^{-2}) by saving 41% of water [mm day^{-1}], and a low sterility. WAS 161, a medium duration type, achieved also a high yield (on average 0.70 kg m^{-2}), yield was even higher in the SSC and sterility lower. IR 64 yielded on average 0.66 kg m^{-2}, and Jaya 0.64 kg m^{-2}. In the SSC IR 64 achieved a higher yield and Jaya a higher tiller number.

Sahel 108, IR 31785 and WAS 6322 did perform well. They all achieved reasonable yields but their water saving potential was rather low. For example 15% water savings were measured for WAS 6322, which achieved also the highest HI (0.58).

The genotype IR 4630, a long duration type, saved 17% of water, but yield was very low especially in the SSC, due to the high sterility of 56%.

Statements about Chomrong and CG 14 as traditional cultivars with short crop durations were not possible because of the damage caused by birds which affected yield and sterility strongly.

7 Conclusion & Outlook

At the WARDA-Sahel-Station the implementation of SSC during rainy season was successful as it was possible to achieve the same yield with 24% less water input. Therefore this system could be applied in similar environments.

Neither the accumulation of biomass nor tiller number was negatively affected in SSC. Phenological development in the SSC differed to the CPS, however, without any detrimental effect on the yield.

Promising genotypes were found in WAS 161, Sahel 202 and Jaya. They all performed very well in SSC due to traits such as high water productivity, early vigor and strong remobilisation force assuring high yields.

Site-specific conditions were favourable for applying water saving methods such as SSC. This was due to the shallow water table and the high clay content which assured good water holding capacities.

Some issues do require further clarification to confirm the results of this study:

- More detailed studies concerning evaporation, transpiration and seepage losses are required for a better evaluation of the different water losses and to focus on further possibilities to save water.
- More studies for both seasons (rainy and dry) have to be conducted to further study the possible influence of heat (rainy season) and cold stress (dry season) on rice.
- More detailed studies in terms of certain promising cultivars as WAS 161 and Sahel 202 are necessary to validate promising traits identified in this study for the dry season in SSC
- Promising traits for SSC such as an early, high specific leaf area (weed competitiveness), an early vigor, low transpiration rate and high drought resistance should be studied.
- Additionally it should be tested if farmers would accept and could apply this water saving system, as these techniques require accurate water delivery and exact timing.

- Study the long term and large scale effects of water saving irrigation in regard to salinisation by capillary rise and the groundwater table, which could decrease due to less percolation.

It is necessary to estimate the risks which can occur by applying water saving production systems, e.g.: decrease in biomass and yield, higher weed density, and an increase in spikelet sterility. All these factors reduce the returns of rice production, eventually discouraging farmers from adopting such irrigation systems. Because of a steadily rising fuel price and water scarcity a minimization of water input into agricultural production is required to save water and reduce energy costs for pumping.

Changing from flooded to non-flooded rice production requires breeding of adapted varieties and the development of appropriate water and crop management practices. There is a strong need to develop site-specific production technologies so that in each rice production zone across the continent the optimal and environmentally sound way of cropping rice can be established (Farooq et al. 2009). Especially by taking into account the dynamics and risks of climatic changes a holistic approach is needed.

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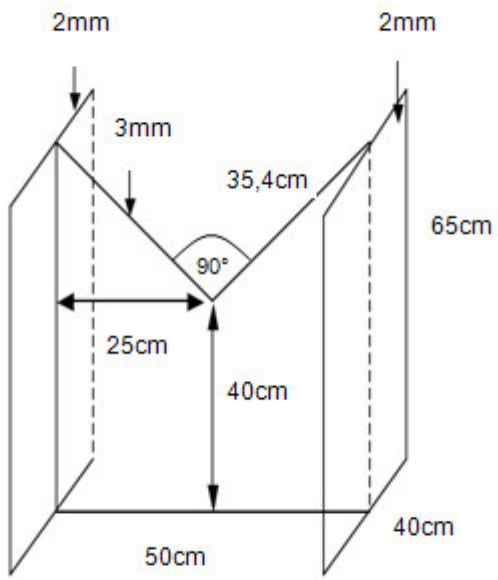
Appendix

Appendix 1: Draft of a V-notch weir used in the experiment to measure amount of irrigation-water



Source: Solenne Guillaume

Appendix 2: Unit Conversion in V-notch formula

The original King and Brater formula is:

$$Q = 2.5 \tan(\theta/2)\, H^{2.5}$$

Where:

Q = Theoretical discharge ($ft^3\ sec^{-1}$)
θ = Angle of V- notch (degrees)

H = Head on apex of notch (ft)
2.5 = constant ($ft^{0.5}\ sec^{-1}$)

To obtain Q in $cm^3\ s^{-1}$, H should be measured in cm and the constant converted into $cm^{0.5}\ s^{-1}$.

$$\frac{cm^{0.5}}{s} = \frac{ft^{0.5}}{s} * \frac{cm^{0.5}}{ft^{0.5}} = \frac{ft^{0.5}}{s} * \frac{30.45^{0.5}}{1^{0.5}} = \frac{ft^{0.5}}{s} * 5.5$$

So the constant is now equal to 13.8 ($cm^{0.5}s^{-1}$) and the King an Brater formula is

$$Q = 13.8 \tan(\theta/2)\, H^{2.5}$$

Where

- Q = Theoretical discharge ($cm^3\ sec^{-1}$)
- θ = Angle of V- notch weir (degrees)
- H = Head on apex of notch (cm)
- 13.8 = constant ($cm^{0.5}\ sec^{-1}$)

The discharge calculated in $cm^3\ s^{-1}$ was converted into L min^{-1}:

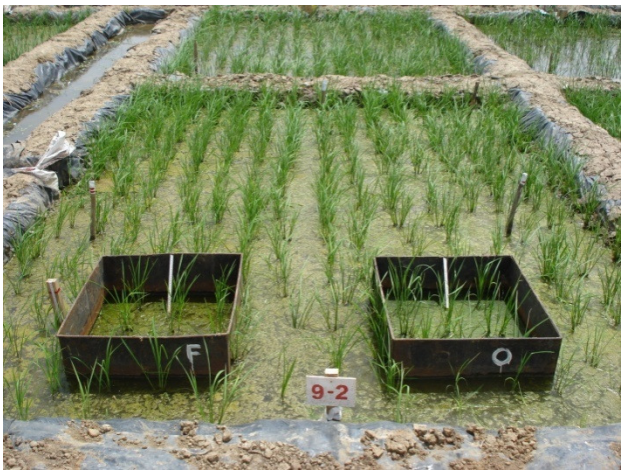
$$Q\frac{l}{min} = Q\ \frac{cm^3}{s} * \frac{s}{min} * \frac{l}{cm^3} = Q\frac{cm^3}{s} * 60 * \frac{1}{1000}$$

Appendix 3: Tiller number [m^{-2}] in detail for the 2 irrigation-systems (Conventional Paddy System (CPS), Saturated Soil Conditions (SSC))

Variety	Tiller [no] 21DAS		Tiller [no] 41 DAS		Tiller [no] 62 DAS		Tiller [no] 84 DAS	
	CPS	SSC	CPS	SSC	CPS	SSC	CPS	SSC
CG 14	100	125	475	546	648	692	365	452
Chomrong	133	100	385	327	408	479		
IR 31785-58-1-2-3-3	154	106	494	531	594	577	515	527
IR 4630-22-2	183	140	558	390	504	571	473	496
IR 64	200	135	690	633	558	621	477	565
JAYA	204	169	479	612.5	508	644	381	458
Sahel 108	221	121	752	477	602	638	400	529
Sahel 202	*102*	*58*	*388*	*306*	442	513	394	458
WAS 6322	179	163	615	571	571	600	510	533
WAS 161-B 9-2	169	123	644	671	569	602	517	475

Appendix 4: Pictures of the field layout and lysimeters

Picture 4: Field layout



Picture 5: Lysimeter in a plot

Appendix 5.1: Dry matter [g hill^{-1}] for the first sampling (30.07.2008, 21 DAS), for the 10 varieties in the CPS and SSC; AV=average, SE=standard error, Rep=replication

DM Leaves total [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	0.11	0.27	0.16	0.52	0.09	0.42	0.43	0.35	0.32	0.38
		2	0.29	0.15	0.17	0.20	0.11	0.15	0.16	0.35	0.25	0.29
		3	0.24	0.24	0.16	0.13	0.06	0.07	0.09	0.14	0.22	0.13
		AV	0.21	0.22	0.17	0.28	0.09	0.21	0.23	0.28	0.26	0.27
		SE	0.05	0.04	0.00	0.12	0.01	0.11	0.10	0.07	0.03	0.07
	SSC	1	0.10	0.28	0.16	0.49	0.10	0.10	0.35	0.53	0.32	0.37
		2	0.17	0.14	0.18	0.18	0.12	0.05	0.33	0.33	0.24	0.27
		3	0.23	0.24	0.16	0.13	0.06	0.09	0.14	0.14	0.22	0.14
		AV	0.17	0.22	0.17	0.27	0.09	0.08	0.28	0.34	0.26	0.26
		SE	0.04	0.04	0.01	0.11	0.02	0.02	0.07	0.11	0.03	0.07
DM tiller [g]												
	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	0.11	0.29	0.21	0.45	0.06	0.41	0.29	0.51	0.46	0.37
		2	0.29	0.17	0.17	0.19	0.07	0.15	0.34	0.35	0.25	0.31
		3	0.27	0.23	0.19	0.10	0.05	0.08	0.12	0.09	0.23	0.21
		AV	0.22	0.23	0.19	0.25	0.06	0.21	0.25	0.32	0.31	0.30
		SE	0.06	0.03	0.01	0.11	0.01	0.10	0.07	0.12	0.08	0.05
	SSC	1	0.11	0.28	0.23	0.27	0.06	0.07	0.29	0.50	0.50	0.38
		2	0.17	0.17	0.17	0.19	0.07	0.02	0.34	0.35	0.24	0.30
		3	0.28	0.23	0.20	0.15	0.05	0.06	0.13	0.10	0.23	0.25
		AV	0.19	0.23	0.20	0.20	0.06	0.05	0.25	0.32	0.32	0.31
		SE	0.05	0.03	0.02	0.04	0.01	0.01	0.06	0.12	0.09	0.04
DM root [g]												
	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	0.17	0.37	0.24	0.61	0.06	0.75	0.61	0.95	0.27	0.59
		2	0.37	0.18	0.37	0.11	0.12	0.29	0.68	0.15	0.43	0.09
		3	0.32	0.36	0.07	0.11	0.11	0.09	0.42	0.13	0.32	0.53
		AV	0.29	0.30	0.23	0.28	0.10	0.38	0.57	0.41	0.34	0.40
		SE	0.06	0.06	0.09	0.17	0.02	0.19	0.08	0.27	0.05	0.16
	SSC	1	0.06	0.10	0.22	0.11	0.12	0.16	0.78	0.03	0.15	0.18
		2	0.43	0.13	0.36	0.11	0.19	0.16	0.18	0.30	0.12	0.09
		3	0.17	0.19	0.26	0.15	0.07	0.16	0.14	0.32	0.41	0.15
		AV	0.22	0.14	0.28	0.12	0.13	0.16	0.36	0.22	0.23	0.14
		SE	0.11	0.03	0.04	0.01	0.04	0.00	0.21	0.09	0.09	0.03
DM [g]												
	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	0.39	0.93	0.61	1.59	0.21	1.58	1.33	1.81	1.06	1.34
		2	0.96	0.50	0.71	0.50	0.29	0.58	1.17	0.85	0.92	0.69
		3	0.83	0.84	0.43	0.34	0.23	0.24	0.64	0.36	0.77	0.87
		AV	0.73	0.76	0.58	0.81	0.24	0.80	1.05	1.01	0.92	0.97
		SE	0.17	0.13	0.08	0.39	0.03	0.40	0.21	0.43	0.08	0.19
	SSC	1	0.27	0.67	0.60	0.87	0.28	0.33	1.42	1.07	0.97	0.93
		2	0.77	0.44	0.71	0.48	0.38	0.24	0.85	0.99	0.61	0.67
		3	0.68	0.66	0.63	0.44	0.19	0.31	0.40	0.56	0.87	0.55
		AV	0.57	0.59	0.65	0.59	0.28	0.30	0.89	0.87	0.81	0.72
		SE	0.15	0.07	0.03	0.14	0.06	0.03	0.30	0.16	0.11	0.11

Appendix 5.2: Dry matter [g hill^{-1}] for the second sampling (20.08.2008, 42 DAS), for the 10 varieties in the CPS and SSC; AV=average, SE=standard error, Rep=replication

	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
DM Leaves total [g]	CPS	1	3.95	3.14	3.33	5.31	4.47	2.63	3.10	3.00	3.13	6.11
		2	2.58	2.97	4.78	2.90	2.45	2.03	3.21	5.00	3.67	4.04
		3	5.52	5.57	4.51	1.79	3.70	0.89	4.65	4.05	3.73	4.33
		AV	4.02	3.90	4.21	3.33	3.54	1.85	3.65	4.02	3.51	4.83
		SE	0.85	0.84	0.45	1.04	0.59	0.51	0.50	0.58	0.19	0.65
	SSC	1	3.96	0.87	1.96	4.88	4.26	2.14	3.33	1.48	3.68	1.77
		2	3.47	3.34	4.96	2.15	3.31	0.53	3.46	3.60	2.48	2.63
		3	2.15	1.90	2.57	2.20	2.70	0.98	3.45	3.49	3.12	2.98
		AV	3.19	2.03	3.16	3.08	3.43	1.22	3.41	2.85	3.09	2.46
		SE	0.54	0.72	0.92	0.90	0.45	0.48	0.04	0.69	0.35	0.36
DM tiller [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	5.76	3.97	4.63	8.49	4.29	3.06	4.62	3.15	4.09	7.57
		2	2.58	3.08	6.96	2.61	2.31	2.56	3.24	6.43	4.23	4.54
		3	7.92	7.59	6.28	2.26	4.00	0.98	7.23	5.02	6.07	5.73
		AV	5.42	4.88	5.95	4.45	3.53	2.20	5.03	4.87	4.80	5.94
		SE	1.55	1.38	0.69	2.02	0.62	0.63	1.17	0.95	0.64	0.88
	SSC	1	4.78	1.20	2.70	5.81	3.92	2.65	5.81	1.40	4.71	2.32
		2	5.15	4.36	8.69	2.47	4.05	0.33	3.04	3.66	3.30	2.32
		3	2.48	2.65	3.18	3.14	3.43	1.29	3.71	4.11	4.45	3.45
		AV	4.13	2.74	4.86	3.80	3.80	1.43	4.18	3.05	4.15	2.69
		SE	0.84	0.91	1.92	1.02	0.19	0.67	0.84	0.84	0.43	0.38
DM roots [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	2.36	5.27	3.71	6.59	6.04	3.70	3.45	5.44	10.11	18.11
		2	1.40	3.63	5.41	2.16	1.30	4.74	2.20	16.10	9.33	3.94
		3	3.30	13.86	4.01	1.18	4.47	0.43	12.50	5.90	4.48	4.67
		AV	2.35	7.59	4.38	3.31	3.94	2.96	6.05	9.15	7.97	8.91
		SE	0.55	3.17	0.52	1.66	1.39	1.30	3.25	3.48	1.76	4.61
	SSC	1	5.63	1.06	3.24	2.89	2.34	1.30	4.07	1.61	5.26	1.46
		2	5.73	8.43	7.03	1.20	1.90	0.32	4.22	4.10	0.98	3.20
		3	2.90	2.79	6.80	1.39	3.00	1.08	4.66	3.80	3.32	4.06
		AV	4.75	4.09	5.69	1.83	2.41	0.90	4.32	3.17	3.19	2.91
		SE	0.93	2.23	1.23	0.53	0.32	0.30	0.18	0.78	1.24	0.76
DM [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	12.07	12.38	11.67	20.39	14.80	9.39	11.16	11.59	17.32	31.78
		2	6.56	9.68	17.15	7.66	6.06	9.33	8.65	27.52	17.23	12.52
		3	16.74	27.03	14.81	5.22	12.17	2.29	24.38	14.97	14.28	14.73
		AV	11.79	16.36	14.54	11.09	11.01	7.00	14.73	18.03	16.28	19.68
		SE	2.94	5.39	1.59	4.70	2.59	2.35	4.88	4.85	1.00	6.09
	SSC	1	14.37	3.12	7.90	13.58	10.52	6.10	13.21	4.49	13.65	5.54
		2	14.35	16.13	20.68	5.82	9.25	1.18	10.72	11.36	6.76	8.15
		3	7.52	7.34	12.55	6.73	9.13	3.35	11.82	11.39	10.88	10.48
		AV	12.08	8.86	13.71	8.71	9.63	3.54	11.91	9.08	10.43	8.06
		SE	2.28	3.83	3.74	2.45	0.44	1.42	0.72	2.30	2.00	1.43

Appendix 5.3: Dry matter [g hill^{-1}] for the third sampling (10.09.2008, 62 DAS), for the 10 varieties in the CPS and SSC; AV=average, SE=standard error, Rep=replication

	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
DM Leaves total [g]	CPS	1	6.56	8.42	9.98	7.66	12.00	10.49	7.25	8.84	9.07	9.83
		2	7.93	7.10	12.26	3.49	10.55	12.97	8.45	10.00	10.30	8.31
		3	9.78		8.75	6.27	13.25	7.65	10.67	8.47	8.44	10.44
		AV	8.09	7.76	10.33	5.81	11.93	10.37	8.79	9.10	9.27	9.53
		SE	0.93	0.54	1.03	1.23	0.78	1.54	1.00	0.46	0.54	0.63
	SSC	1	10.70	9.14	8.43	8.60	13.44	7.14	6.79	8.62	11.04	13.51
		2	12.58	8.26	9.94	7.58	9.52	5.99	9.33	5.58	11.38	10.52
		3	8.93	15.11	7.38	7.82	11.69	6.89	11.15	10.97	10.15	14.02
		AV	10.73	10.84	8.58	8.00	11.55	6.67	9.09	8.39	10.86	12.68
		SE	1.05	2.15	0.74	0.31	1.13	0.35	1.27	1.56	0.36	1.09
DM tiller [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	16.18	13.50	13.90	21.55	23.73	13.55	12.53	16.38	15.50	20.13
		2	14.33	10.23	16.68	7.38	15.45	23.85	12.53	21.73	17.70	17.90
		3	20.30		18.60	16.88	18.90	11.18	20.85	14.03	13.25	27.60
		AV	16.93	11.86	16.39	15.27	19.36	16.19	15.30	17.38	15.48	21.88
		SE	1.77	1.64	1.36	4.17	2.40	3.89	2.78	2.28	1.28	2.93
	SSC	1	16.63	15.93	17.23	13.08	26.95	7.23	10.43	16.50	18.80	23.40
		2	20.43	10.83	15.60	17.93	14.80	4.38	12.80	8.60	21.38	13.90
		3	17.28	26.58	17.35	22.33	19.85	10.95	15.75	16.80	18.73	21.48
		AV	18.11	17.78	16.73	17.78	20.53	7.52	12.99	13.97	19.63	19.59
		SE	1.17	5.68	0.56	2.67	3.52	1.90	1.54	2.68	0.87	2.90
DM root [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	22.74	21.92	23.88	29.21	35.73	24.04	19.78	25.21	24.57	29.96
		2	22.26	17.32	28.94	10.86	26.00	36.82	20.98	31.73	28.00	26.21
		3	30.08		27.35	23.14	32.15	18.82	31.52	22.50	21.69	38.04
		AV	25.02	19.62	26.72	21.07	31.29	26.56	24.09	26.48	24.75	31.40
		SE	2.53	2.30	1.49	5.40	2.84	5.35	3.73	2.74	1.82	3.49
	SSC	1	27.32	25.06	25.66	21.67	40.39	14.37	17.21	25.12	29.84	36.91
		2	33.01	19.08	25.54	25.50	24.32	10.37	22.13	14.18	32.75	24.42
		3	26.20		24.73	30.14	31.54	17.84	26.90	27.77	28.88	35.49
		AV	28.84	22.07	25.31	25.77	32.08	14.19	22.08	22.35	30.49	32.27
		SE	2.11	2.99	0.29	2.45	4.65	2.16	2.80	4.16	1.16	3.95
DM dead leaves [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	1.90	0.60	2.60	2.10	4.00	4.00	1.10	3.70	2.20	4.20
		2	1.10	1.30	4.80	2.60	4.40	3.30	1.60	9.40	5.30	6.70
		3	5.50		2.80	1.20	6.20	1.50	2.30	2.10	2.30	5.00
		AV	2.83	0.95	3.40	1.97	4.87	2.93	1.67	5.07	3.27	5.30
		SE	1.35	0.35	0.70	0.41	0.68	0.74	0.35	2.22	1.02	0.74
	SSC	1	1.30	2.60	3.50	0.70	15.40	0.60	1.30	3.00	2.60	14.80
		2	3.30	0.90	1.60	5.30	3.70	0.00	1.20	1.00	5.50	4.50
		3	2.00	7.00	5.40	0.60	4.50	1.70	3.70	2.70	2.30	4.20
		AV	2.20	3.50	3.50	2.20	7.87	0.77	2.07	2.23	3.47	7.83
		SE	0.59	2.23	1.10	1.55	3.77	0.50	0.82	0.62	1.02	3.48
DM panicle (4 plants)	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	3.4		2.6	27.1				10.8		1.1
		2				3.1		19.9		19.5		13.2
		3	2.3			16.1	3.6			2.9		7.3
		AV	2.85		2.60	15.43	3.60	19.90		11.07		7.20
		SE	0.55			6.94				4.79		3.49
	SSC	1	3.90			15.70	3.40			5.80	1.60	
		2	8.90		0.40	17.60				2.50		
		3	2.70			25.20	10.90			3.60	0.60	1.00
		AV	5.17		0.40	19.50	7.15			3.97	1.10	1.00
		SE	1.90			2.90	3.75			0.97	0.41	

DM [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	27.86	28.17	28.48	40.91	42.93	31.64	24.35	31.94	28.92	37.78
		2	24.93	26.15	33.84	13.59	31.60	42.62	23.58	45.55	33.52	34.49
		3	34.53		31.15	29.07	37.40	30.20	41.89	25.55	25.07	48.92
		AV	29.11	27.16	31.16	27.86	37.31	34.82	29.94	34.35	29.17	40.40
		SE	2.84	1.01	1.55	7.91	3.27	3.92	5.98	5.90	2.44	4.37
	SSC	1	31.72	32.51	37.23	27.77	51.19	19.32	22.54	36.32	39.89	46.61
		2	42.46	25.21	31.04	33.33	29.24	11.47	26.53	18.05	37.03	30.35
		3	39.88	50.24	32.58	41.29	49.19	30.46	34.03	37.84	36.00	44.59
		AV	38.02	35.99	33.62	34.13	43.21	20.42	27.70	30.74	37.64	40.52
		SE	3.24	9.10	1.86	3.92	7.01	5.51	3.37	6.36	1.16	5.12

Appendix 5.4: Dry matter [g hill^{-1}] for the fourth sampling (02.10.2008, 84 DAS), for the 10 varieties in the CPS and SSC; AV=average, SE=standard error, Rep=replication

DM Leaves [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	5.30	10.37	8.92	harvested	6.41	8.59	11.71	6.59	9.81	3.41
		2	4.06	12.71	8.19		1.37	13.46	18.63	6.85	5.80	7.76
		3	3.12	8.74	8.30		5.04	8.19	4.86	6.12	6.34	5.55
		AV	4.16	10.61	8.47		4.27	10.08	11.73	6.52	7.31	5.57
		SE	0.63	1.15	0.23		1.50	1.70	3.98	0.21	1.26	1.26
	SSC	1	8.88	14.19	11.13		4.21	24.92	15.31	6.04	5.86	5.05
		2	12.03	24.26	14.93		5.44	11.21	18.05	7.48	12.04	7.77
		3	3.64	11.28	15.52		5.97	15.32	9.17	9.72	9.63	8.33
		AV	8.18	16.58	13.86		5.20	17.15	14.18	7.75	9.18	7.05
		SE	2.45	3.93	1.38		0.52	4.06	2.63	1.07	1.80	1.01

DM tiller [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	16.85	35.95	22.18		21.75	18.25	32.03	15.25	28.10	14.13
		2	17.08	33.48	19.65		31.08	24.35	36.20	15.33	8.25	12.65
		3	18.25	26.65	19.35		15.93	21.05	30.78	17.80	19.30	15.35
		AV	17.39	32.03	20.39		22.92	21.22	33.00	16.13	18.55	14.04
		SE	0.43	2.78	0.90		4.41	1.76	1.64	0.84	5.74	0.78
	SSC	1	19.98	41.85	33.88		32.83	27.00	30.08	15.90	22.80	18.03
		2	23.28	29.73	22.60		25.08	28.13	33.48	16.43	35.73	21.08
		3	15.45	37.28	22.98		44.53	28.33	13.75	21.10	25.40	20.23
		AV	19.57	36.28	26.48		34.14	27.82	25.77	17.81	27.98	19.78
		SE	2.27	3.54	3.70		5.65	0.41	6.09	1.65	3.95	0.91

DM roots [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	8.50	5.70	5.80		2.90	3.80	3.00	1.60	4.80	6.00
		2	4.80	3.90	4.30		2.00	2.40	4.80	2.90	4.30	4.80
		3	3.70	4.30	5.20		3.50	3.20	5.70	2.30	4.70	9.30
		AV	5.67	4.63	5.10		2.80	3.13	4.50	2.27	4.60	6.70
		SE	1.45	0.55	0.44		0.44	0.41	0.79	0.38	0.15	1.35
	SSC	1	3.10	3.00	2.80		5.80	3.20	2.20	3.60	2.80	4.00
		2	2.10	4.00	5.70		7.40	3.10	2.70	2.40	2.40	5.30
		3	0.90	3.90	1.00		1.70	2.80	1.10	3.40	1.80	3.60
		AV	2.03	3.63	3.17		4.97	3.03	2.00	3.13	2.33	4.30
		SE	0.64	0.32	1.37		1.70	0.12	0.47	0.37	0.29	0.51

DM dead leaves [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	24.20	26.40	15.00		10.10	12.20	8.30	14.00	28.20	22.10
		2	16.40	8.40	13.90		61.20	18.50	28.70	18.50	27.50	22.40
		3	17.90	12.00	28.20		23.00	20.10	41.90	25.10	23.90	38.90
		AV	19.50	15.60	19.03		31.43	16.93	26.30	19.20	26.53	27.80
		SE	2.39	5.50	4.59		15.34	2.41	9.77	3.22	1.33	5.55
	SSC	1	19.60	26.40	14.90		60.70	14.00	21.20	21.20	31.10	30.90
		2	11.70	16.90	15.80		31.60	11.20	14.30	26.90	18.90	19.50
		3	25.20	12.00	25.50		71.50	13.60	6.80	22.20	17.50	23.20
		AV	18.83	18.43	18.73		54.60	12.93	14.10	23.43	22.50	24.53
		SE	3.92	4.23	3.39		11.92	0.87	4.16	1.76	4.32	3.36
DM panicle (4 plants)	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	91.9		72.9		66.8	19.4	44.4	91.5	87.5	100.9
		2	106.5	6.4	75.0		81.1	18.8	41.5	100.4	84.3	100.9
		3	86.1		79.2		48.7		36.4	96.2	64.2	102.8
		AV	94.83	6.40	75.70		65.53	19.10	40.77	96.03	78.67	101.53
		SE	6.07		1.85		9.37	0.30	2.34	2.57	7.29	0.63
	SSC	1	99.90		38.90		69.20	2.40	26.90	73.80	55.50	62.10
		2	63.10	1.50	89.40		48.20		14.10	94.60	66.60	67.50
		3	70.30		19.70		97.80	2.20	4.60	110.40	77.20	59.20
		AV	77.77	1.50	49.33		71.73	2.30	15.20	92.93	66.43	62.93
		SE	11.26		20.79		14.37	0.08	6.46	10.60	6.26	2.43
DM [g]	Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
	CPS	1	59.67	58.62	58.87		50.28	38.54	59.91	49.82	71.63	54.29
		2	56.66	53.79	54.36		70.02	49.54	77.18	54.80	46.30	56.03
		3	51.07	42.69	59.70		42.39	37.46	60.91	56.55	52.36	65.63
		AV	55.80	51.70	57.65		54.23	41.85	66.00	53.72	56.76	58.65
		SE	2.52	4.72	1.66		8.22	3.86	5.60	2.02	7.64	3.53
	SSC	1	61.83	65.64	61.25		75.31	59.22	59.61	49.29	53.11	50.33
		2	56.10	62.58	69.53		57.86	45.23	61.33	56.68	71.54	55.90
		3	43.87	55.46	50.79		94.52	50.39	26.87	67.37	60.51	52.76
		AV	53.93	61.23	60.53		75.90	51.61	49.27	57.78	61.72	52.99
		SE	5.30	3.02	5.42		10.59	4.08	11.21	5.25	5.35	1.61

Appendix 6.1: Tiller number [tillers hill^{-1}] for the first sampling date for ten varieties in the CPS and SSC; 30.07.08=21 DAS, 20.08.08=41 DAS; 09.09.08=62 DAS, 02.10.08=84 DAS; AV=average, SE=standard error, Rep=replication

Treat-ment	Rep.	hill	30.7.08 IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
CPS	**1**	**1**	7	9	6	6	6	7	11	9	9	8
		2	8	10	7	6	6	11	11	8	5	8
		3	6	8	8	7	2	8	11	9	7	14
		4	7	8	8	6	3	5	7	10	5	13
		AV	7	8.75	7.25	6.25	4.25	7.75	10	9	6.5	10.75
	2	**1**	4	5	8	3	2	2	9	6	7	6
		2	5	4	10	4	4	3	11	5	7	6
		3	3	4	8	7	3	2	3	5	8	7
		4	4	4	11	6	3	3	6	9	8	10
		AV	4	4.25	9.25	5	3	2.5	7.25	6.25	7.5	7.25
	3	**1**	8	10	8	5	4	2	7	6	5	9
		2	8	8	6	4	4	2	6	5	6	8
		3	6	8	8	5	4	2	8	8	7	9
		4	8	10	8	5	6	2	8	6	7	8
		AV	7.5	9	7.5	4.75	4.5	2	7.25	6.25	6.25	8.5
		SE	0.60	0.81	0.47	0.41	0.48	1.01	0.85	0.62	0.43	0.83
SSC	**1**	**1**	3	4	5	4	3	2	8	6	3	2
		2	5	3	5	4	6	3	7	7	3	2
		3	4	4	6	4	2	2	8	2	3	5
		4	4	4	5	3	3	2	10	5	3	5
		AV	4	3.75	5.25	3.75	3.5	2.25	8.25	5	3	3.5
	2	**1**	4	8	8	2	6	2	5	9	5	8
		2	3	6	7	4	6	2	7	11	7	5
		3	7	7	5	6	5	2	4	7	9	5
		4	3	6	5	6	9	3	10	5	5	5
		AV	4.25	6.75	6.25	4.5	6.5	2.25	6.5	8	6.5	5.75
	3	**1**	3	7	3	4	5	2	4	8	6	5
		2	3	6	4	7	4	2	8	4	5	6
		3	6	6	6	4	5	3	5	8	4	5
		4	6	6	6	5	5	3	5	6	6	5
		AV	4.5	6.25	4.75	5	4.75	2.5	5.5	6.5	5.25	5.25
		SE	0.47	0.50	0.44	0.46	0.61	0.16	0.71	0.80	0.63	0.53

Appendix 6.2: Tiller number [tillers hill^{-1}] for the second sampling date for ten varieties in the CPS and SSC; 20.08.08=42 DAS; AV=average, SE=standard error, Rep=replication

Treat-ment	Rep.	hill	20.8.08 IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
CPS	**1**	**1**	25	22	29	25	40	13	19	16	23	22
		2	22	27	15	17	11	19	15	39	26	34
		3	18	18	26	17	19	29	10	12	26	47
		4	19	19	34	25	23	24	19	24	20	56
		AV	21	21.5	26	21	23.25	21.25	15.75	22.75	23.75	39.75
	2	**1**	30	17	22	19	8	18	12	16	18	16
		2	14	15	20	14	27	20	10	12	28	25
		3	12	22	28	14	11	22	16	30	46	18
		4	15	13	35	8	4	7	14	24	17	21
		AV	17.75	16.75	26.25	13.75	12.5	16.75	13	20.5	27.25	20
	3	**1**	25	31	26	11	12	11	27	33	29	23
		2	24	29	42	19	25	5	21	30	29	31
		3	17	25	35	6	29	10	35	12	27	45
		4	16	30	20	10	19	8	32	47	20	23
		AV	20.5	28.75	30.75	11.5	21.25	8.5	28.75	30.5	26.25	30.5
		SE	1.81	2.03	2.60	2.04	3.45	2.52	2.76	3.84	2.56	4.28
SSC	**1**	**1**	13	10	18	31	47	7	37	17	17	13
		2	12	5	13	13	23	14	14	11	24	11
		3	46	10	10	20	24	15	11	12	20	18
		4	27	5	15	20	19	29	23	13	18	14
		AV	24.5	7.5	14	21	28.25	16.25	21.25	13.25	19.75	14
	2	**1**	31	30	39	16	17	8	20	16	21	13
		2	16	27	50	7	27	8	16	10	16	47
		3	24	12	24	6	18	9	26	19	10	12
		4	28	35	34	10	17	8	36	30	20	23
		AV	24.75	26	36.75	9.75	19.75	8.25	24.5	18.75	16.75	23.75
	3	**1**	4	15	10	10	23	13	29	45	69	23
		2	12	10	23	5	13	16	42	23	39	22
		3	28	16	43	9	14	12	18	49	28	16
		4	14	12	25	10	20	8	22	29	40	17
		AV	14.5	13.25	25.25	8.5	17.5	12.25	27.75	36.5	44	19.5
		SE	3.84	3.27	4.46	2.51	2.98	2.05	3.26	4.36	5.33	3.26

Appendix 6.3: Tiller number [tillers hill^{-1}] for the third sampling date for ten varieties in the CPS and SSC; 09.09.08=61 DAS; AV=average, SE=standard error, Rep=replication

Treat-ment	Rep.	hill	9.9.08 IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
CPS	**1**	**1**	20	23	29	14	25	11	18	23	28	24
		2	22	20	21	11	38	16	20	18	21	25
		3	20	24	20	11	20	15	22	22	30	20
		4	22	20	27	13	24	18	23	21	19	18
		AV	21	21.75	24.25	12.25	26.75	15	20.75	21	24.5	21.75
	2	**1**	26	17	15	22	21	15	20	27	24	20
		2	27	14	17	17	35	17	19	23	19	26
		3	24	22	18	24	28	12	26	21	24	26
		4	22	23	20	26	26	18	20	26	18	23
		AV	24.75	19	17.5	22.25	27.5	15.5	21.25	24.25	21.25	23.75
	3	**1**	26	20	27	22	25	21	17	22	24	23
		2	23	19	29	12	20	22	18	22	20	24
		3	25	19	21	12	27	26	21	26	22	25
		4	28	21	24	12	22	21	20	23	24	35
		AV	25.5	19.75	25.25	14.5	23.5	22.5	19	23.25	22.5	26.75
		SE	0.89	0.93	1.59	1.87	1.88	1.44	0.82	0.84	1.22	1.42
SSC	**1**	**1**	22	20	23	19	22	23	22	24	20	25
		2	21	23	29	17	28	21	24	20	22	31
		3	19	19	24	16	29	20	31	21	21	23
		4	25	26	28	14	24	20	27	26	25	24
		AV	21.75	22	26	16.5	25.75	21	26	22.75	22	25.75
	2	**1**	27	25	23	25	31	17	23	19	28	25
		2	24	22	19	22	27	21	26	17	25	22
		3	22	25	27	17	22	22	30	28	27	25
		4	21	21	22	17	29	24	27	23	26	22
		AV	23.5	23.25	22.75	20.25	27.25	21	26.5	21.75	26.5	23.5
	3	**1**	20	22	27	26	32	20	26	28	28	29
		2	29	24	25	22	23	19	25	29	24	26
		3	25	25	29	17	33	19	26	28	18	26
		4	22	22	22	18	32	20	22	25	25	28
		AV	24	23.25	25.75	20.75	30	19.5	24.75	27.5	23.75	27.25
		SE	0.99	0.74	1.06	1.25	1.35	0.63	0.94	1.34	1.07	0.92

Appendix 6.4: Tiller number [tillers hill^{-1}] for the fourth sampling date for ten varieties in the CPS and SSC; 02.10.08=84 DAS; AV=average, SE=standard error, Rep=replication

Treat-ment	Rep.	hill	2.10.08 IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
CPS	**1**	**1**	24	16	21	**harvested**	14	14	14	23	22	22
		2	21	16	23		16	18	12	20	23	15
		3	26	17	24		14	19	15	22	22	17
		4	23	18	23		14	19	17	24	20	14
		AV	23.5	16.75	22.75		14.5	17.5	14.5	22.25	21.75	17
	2	**1**	17	24	22		15	16	17	18	24	17
		2	18	20	20		17	16	15	19	24	15
		3	19	21	14		13	15	14	20	19	14
		4	18	20	15		14	15	12	18	20	16
		AV	18	21.25	17.75		14.75	15.5	14.5	18.75	21.75	15.5
	3	**1**	21	21	17		15	15	19	23	14	15
		2	21	19	19		13	14	18	21	17	14
		3	20	18	15		14	13	15	19	22	17
		4	19	17	16		16	15	15	18	21	16
		AV	20.25	18.75	16.75		14.5	14.25	16.75	20.25	18.5	15.5
		SE	0.89	0.80	1.19		0.41	0.65	0.73	0.72	0.98	0.74
SSC	**1**	**1**	26	17	22		15	21	15	22	14	17
		2	21	17	24		17	18	16	19	13	18
		3	17	20	20		17	21	18	24	17	26
		4	16	18	21		14	20	20	23	15	19
		AV	20	18	21.75		15.75	20	17.25	22	14.75	20
	2	**1**	24	23	22		20	22	14	17	19	24
		2	20	20	23		19	25	16	17	17	23
		3	18	25	20		21	19	18	18	18	22
		4	20	19	23		18	18	20	20	20	20
		AV	20.5	21.75	22		19.5	21	17	18	18.5	22.25
	3	**1**	17	19	19		22	14	19	25	26	22
		2	24	23	29		15	14	22	27	24	19
		3	25	19	25		17	14	21	25	25	20
		4	25	18	23		22	14	21	19	20	24
		AV	22.75	19.75	24		19	14	20.75	24	23.75	21.25
		SE	1.20	0.85	0.89		0.92	1.23	0.87	1.15	1.41	0.92

Appendix 7: Phenological data for nine varieties in the two irrigation-treatments (CPS/SSC)

Variety	Treat-ment	Repli-cation	Start Tillering	Panicle Initiation	Booting	Start Heading	100% Heading	50% Anthesis	100% Anthesis	Maturity
IR 31785	**CPS**	**1**	25.07.08	23.08.08	01.09.08	07.09.08	13.09.08	10.09.08	16.09.08	03.10.08
		2	28.07.08	22.08.08	02.09.08	09.09.08	15.09.08	12.09.08	19.09.08	05.10.08
		3	24.07.08	21.08.08	30.08.08	06.09.08	11.09.08	09.09.08	14.09.08	02.10.08
		Average	**25.07.08**	**22.08.08**	**31.08.08**	**07.09.08**	**13.09.08**	**10.09.08**	**16.09.08**	**03.10.08**
	SSC	**1**	30.07.08	26.08.08	31.08.08	06.09.08	13.09.08	10.09.08	16.09.08	03.10.08
		2	30.07.08	27.08.08	05.09.08	14.09.08	20.09.08	17.09.08	23.09.08	12.10.08
		3	28.07.08	26.08.08	06.09.08	11.09.08	18.09.08	15.09.08	21.09.08	10.10.08
		Average	**29.07.08**	**26.08.08**	**03.09.08**	**10.09.08**	**17.09.08**	**14.09.08**	**20.09.08**	**08.10.08**
IR 4630	**CPS**	**1**	25.07.08	11.09.08	21.09.08	27.09.08	06.10.08	30.09.08	09.10.08	27.10.08
		2	28.07.08	10.09.08	22.09.08	29.09.08	08.10.08	01.10.08	10.10.08	27.10.08
		3	24.07.08	09.09.08	20.09.08	30.09.08	08.10.08	03.10.08	11.10.08	28.10.08
		Average	**25.07.08**	**10.09.08**	**21.09.08**	**28.09.08**	**07.10.08**	**01.10.08**	**10.10.08**	**27.10.08**
	SSC	**1**	29.07.08	12.09.08	21.09.08	30.09.08	06.10.08	02.10.08	09.10.08	29.10.08
		2	29.07.08	14.09.08	30.09.08	28.09.08	06.10.08	30.09.08	09.10.08	27.10.08
		3	28.07.08	10.09.08	22.09.08	29.09.08	05.10.08	03.10.08	08.10.08	30.10.08
		Average	**28.07.08**	**12.09.08**	**24.09.08**	**29.09.08**	**05.10.08**	**01.10.08**	**08.10.08**	**28.10.08**
IR 64	**CPS**	**1**	24.07.08	23.08.08	08.09.08	15.09.08	21.09.08	18.09.08	24.09.08	13.10.08
		2	24.07.08	22.08.08	02.09.08	10.09.08	17.09.08	15.09.08	20.09.08	10.10.08
		3	22.07.08	21.08.08	01.09.08	10.09.08	15.09.08	13.09.08	19.09.08	07.10.08
		Average	**23.07.08**	**22.08.08**	**03.09.08**	**11.09.08**	**17.09.08**	**15.09.08**	**21.09.08**	**10.10.08**
	SSC	**1**	27.07.08	26.08.08	04.09.08	11.09.08	18.09.08	14.09.08	20.09.08	08.10.08
		2	30.07.08	27.08.08	03.09.08	11.09.08	18.09.08	15.09.08	21.09.08	10.10.08
		3	29.07.08	25.08.08	07.09.08	14.09.08	19.09.08	17.09.08	22.09.08	12.10.08
		Average	**28.07.08**	**26.08.08**	**04.09.08**	**12.09.08**	**18.09.08**	**15.09.08**	**21.09.08**	**10.10.08**
Chomrong	**CPS**	**1**	28.07.08	23.08.08	25.08.08	31.08.08	03.09.08	02.09.08	06.09.08	25.09.08
		2	24.07.08	20.08.08	24.08.08	30.08.08	05.09.08	03.09.08	08.09.08	24.09.08
		3	30.07.08	18.08.08	26.08.08	31.08.08	07.09.08	03.09.08	09.09.08	25.09.08
		Average	**27.07.08**	**20.08.08**	**25.08.08**	**30.08.08**	**05.09.08**	**02.09.08**	**07.09.08**	**24.09.08**
	SSC	**1**	27.07.08	25.08.08	28.08.08	31.08.08	03.09.08	02.09.08	08.09.08	25.09.08
		2	29.07.08	24.08.08	28.08.08	01.09.08	02.09.08	04.09.08	08.09.08	24.09.08
		3	25.07.08	23.08.08	27.08.08	02.09.08	03.09.08	04.09.08	08.09.08	23.09.08
		Average	**27.07.08**	**24.08.08**	**27.08.08**	**01.09.08**	**02.09.08**	**03.09.08**	**08.09.08**	**24.09.08**
CG 14	**CPS**	**1**	29.07.08	21.08.08	01.09.08	07.09.08	13.09.08	10.09.08	16.09.08	03.10.08
		2	28.07.08	21.08.08	02.09.08	07.09.08	12.09.08	10.09.08	15.09.08	02.10.08
		3	28.07.08	20.08.08	03.09.08	06.09.08	13.09.08	10.09.08	16.09.08	03.10.08
		Average	**28.07.08**	**20.08.08**	**02.09.08**	**06.09.08**	**12.09.08**	**10.09.08**	**15.09.08**	**02.10.08**
	SSC	**1**	29.07.08	27.08.08	01.09.08	08.09.08	13.09.08	09.09.08	16.09.08	03.10.08
		2	28.07.08	25.08.08	02.09.08	09.09.08	16.09.08	12.09.08	18.09.08	05.10.08
		3	29.07.08	26.08.08	01.09.08	09.09.08	15.09.08	11.09.08	17.09.08	04.10.08
		Average	**28.07.08**	**26.08.08**	**01.09.08**	**08.09.08**	**14.09.08**	**10.09.08**	**17.09.08**	**04.10.08**
Jaya	**CPS**	**1**	24.07.08	10.09.08	14.09.08	21.09.08	27.09.08	24.09.08	30.09.08	20.10.08
		2	24.07.08	09.09.08	15.09.08	21.09.08	26.09.08	24.09.08	29.09.08	20.10.08
		3	25.07.08	10.09.08	11.09.08		26.09.08	22.09.08	28.09.08	17.10.08
		Average	**24.07.08**	**09.09.08**	**13.09.08**	**21.09.08**	**26.09.08**	**23.09.08**	**29.09.08**	**19.10.08**
	SSC	**1**	24.07.08	10.09.08	14.09.08	22.09.08	27.09.08	25.09.08	30.09.08	20.10.08
		2	28.07.08	14.09.08	20.09.08	20.09.08	27.09.08	24.09.08	30.09.08	20.10.08
		3	29.07.08	13.09.08	15.09.08	23.09.08	24.09.08	26.09.08	27.09.08	20.10.08
		Average	**27.07.08**	**12.09.08**	**16.09.08**	**21.09.08**	**26.09.08**	**25.09.08**	**29.09.08**	**20.10.08**
WAS 6322	**CPS**	**1**	24.07.08	23.08.08	30.08.08	06.09.08	10.09.08	09.09.08	14.09.08	02.10.08
		2	25.07.08	22.08.08	29.08.08	06.09.08	10.09.08	09.09.08	15.09.08	02.10.08
		3	27.07.08	21.08.08	31.08.08	07.09.08	13.09.08	10.09.08	15.09.08	03.10.08
		Average	**25.07.08**	**22.08.08**	**30.08.08**	**06.09.08**	**11.09.08**	**09.09.08**	**14.09.08**	**02.10.08**
	SSC	**1**	26.07.08	27.08.08	01.09.08	09.09.08	15.09.08	12.09.08	19.09.08	06.10.08
		2	26.07.08	26.08.08	01.09.08	08.09.08	13.09.08	10.09.08	16.09.08	03.10.08
		3	24.07.08	25.08.08	30.08.08	07.09.08	14.09.08	10.09.08	17.09.08	03.10.08
		Average	**25.07.08**	**26.08.08**	**31.08.08**	**08.09.08**	**14.09.08**	**10.09.08**	**17.09.08**	**04.10.08**

Variety	Treat-ment	Repli-cation	Start Tillering	Panicle Initiation	Booting	Start Heading	100% Heading	50% Anthesis	100% Anthesis	Maturity
WAS 161	**CPS**	**1**	24.07.08		08.09.08	16.09.08	21.09.08	19.09.08	24.09.08	14.09.08
		2	26.07.08	22.08.08	02.09.08	11.09.08	18.09.08	15.09.08	20.09.08	10.10.08
		3	28.07.08	21.08.08	08.09.08	10.09.08	19.09.08	15.09.08	20.09.08	10.10.08
		Average	**26.07.08**	**21.08.08**	**06.09.08**	**12.09.08**	**19.09.08**	**16.09.08**	**21.09.08**	**01.10.08**
	SSC	**1**	29.07.08	28.08.08	07.09.08	14.09.08	20.09.08	17.09.08	23.09.08	12.10.08
		2	28.07.08	27.08.08	08.09.08	14.09.08	21.09.08	17.09.08	24.09.08	12.10.08
		3	27.07.08	27.08.08	02.09.08	11.09.08	18.09.08	14.09.08	20.09.08	08.10.08
		Average	**28.07.08**	**27.08.08**	**05.09.08**	**13.09.08**	**19.09.08**	**16.09.08**	**22.09.08**	**10.10.08**
Sahel 108	**CPS**	**1**	24.07.08	22.08.08	04.09.08	19.09.08	16.09.08	16.09.08	22.09.08	11.10.08
		2	23.07.08	21.08.08	05.09.08	19.09.08	17.09.08	17.09.08	23.09.08	12.10.08
		3	22.07.08	21.08.08	03.09.08	18.09.08	15.09.08	15.09.08	21.09.08	10.10.08
		Average	**23.07.08**	**21.08.08**	**04.09.08**	**18.09.08**	**16.09.08**	**16.09.08**	**22.09.08**	**11.10.08**
	SSC	**1**	28.07.08	26.08.08	04.09.08	20.09.08	16.09.08	16.09.08	22.09.08	12.10.08
		2	29.07.08	25.08.08	05.09.08	18.09.08	16.09.08	16.09.08	21.09.08	10.10.08
		3	24.07.08	26.08.08	04.09.08	20.09.08	17.09.08	17.09.08	23.09.08	12.10.08
		Average	**27.07.08**	**25.08.08**	**04.09.08**	**19.09.08**	**16.09.08**	**16.09.08**	**22.09.08**	**11.10.08**

Appendix 8: Yield [kg m^{-2}] in the CPS and SSC for the ten varieties, average of Sterility [%] and Harvest Index; AV=average, SE=standard error, Rep=replication

Treatment	Rep.	IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
CPS	1	0.55	0.43	0.46	0.22	0.21	0.68		0.58	0.60	0.71
	2	0.46	0.46	0.67	0.20	0.14	0.77	0.64	0.65	0.64	0.58
	3	0.75		0.66	0.11	0.11	0.70	0.65	0.58	0.66	0.55
	AV	0.58	0.45	0.60	0.18	0.16	0.71	0.64	0.60	0.64	0.61
	SE	0.09	0.01	0.07	0.03	0.03	0.03	0.01	0.02	0.02	0.05
SSC	1	0.57	0.23	0.53	0.09	0.11	0.64	0.61	0.53	0.63	0.57
	2	0.53	0.18	1.07	0.15	0.13	1.06	0.76	0.72	0.86	0.79
	3	0.75	0.09	0.60	0.06	0.18	0.54	0.59	0.72	0.81	0.78
	AV	0.62	0.17	0.73	0.10	0.14	0.75	0.66	0.66	0.77	0.71
	SE	0.07	0.04	0.17	0.03	0.02	0.16	0.05	0.06	0.07	0.07
Sterility	CPS	53.73	32.48	33.99	34.33	69.90	42.16	48.13	37.64	30.57	36.56
	SSC	39.55	56.11	38.33	57.10	66.47	31.97	28.68	37.10	20.67	38.37
Harvest Index	CPS	0.46	0.37	0.49	0.48	0.28	0.48	0.56	0.60	0.49	0.59
	SSC	0.57	0.28	0.39	0.27	0.35	0.49	0.53	0.56	0.49	0.47

Appendix 9: Detailed data for Sterility [%] and Harvest Index

		CPS			SSC		
Variety	Rep.	Sterility [%]	AV	SE	Sterility [%]	AV	SE
IR 31785	1	48.55	53.73	13.53	31.66	39.55	8.95
	2	33.33			57.41		
	3	79.32			29.59		
IR 4630	1	21.70	32.48	7.11	35.50	56.11	11.50
	2	29.82			57.56		
	3	45.91			75.26		
IR 64	1	18.90	33.99	7.88	43.56	38.33	6.60
	2	37.61			46.22		
	3	45.45			25.22		
Chomrong	1	46.05	34.33	6.29	39.82	57.10	9.50
	2	24.54			72.57		
	3	32.39			58.91		
CG 14	1	49.19	69.90	11.51	51.05	66.47	9.90
	2	88.98			84.92		
	3	71.53			63.45		
Sahel 202	1	44.37	42.16	1.61	29.91	31.97	2.01
	2	43.07			30.03		
	3	39.03			35.99		
Jaya	1	50.95	48.13	7.37	19.48	28.68	4.60
	2	34.19			33.53		
	3	59.25			33.03		
WAS 6322	1	38.36	37.64	2.88	45.03	37.10	4.45
	2	32.34			29.63		
	3	42.23			36.63		
WAS 161	1	32.26	30.57	1.12	24.78	20.67	2.45
	2	31.01			20.92		
	3	28.45			16.30		
Sahel 108	1	41.43	36.56	3.35	51.48	38.37	8.03
	2	38.11			39.86		
	3	30.14			23.77		

		CPS			SSC		
Variety	Rep.	Harvest Index	AV	SE	Harvest Index	AV	SE
IR 31785	1	0.70	0.57	0.07	0.55	0.46	0.12
	2	0.45			0.62		
	3	0.58			0.21		
IR 4630	1	0.34	0.28	0.03	0.31	0.37	0.04
	2	0.23			0.34		
	3	0.28			0.45		
IR 64	1	0.24	0.39	0.10	0.56	0.49	0.04
	2	0.57			0.43		
	3	0.36			0.47		
Chomrong	1	0.26	0.27	0.06	0.48	0.48	0.01
	2	0.18			0.50		
	3	0.38			0.47		
CG 14	1	0.52	0.35	0.09	0.35	0.28	0.03
	2	0.30			0.24		
	3	0.22			0.26		
Sahel 202	1	0.48	0.49	0.05	0.45	0.48	0.01
	2	0.57			0.50		
	3	0.40			0.49		
Jaya	1	0.48	0.53	0.07	0.57	0.56	0.02
	2	0.44			0.53		
	3	0.67			0.59		
WAS 6322	1	0.57	0.56	0.06	0.58	0.60	0.02
	2	0.66			0.63		
	3	0.45			0.58		
WAS 161	1	0.45	0.49	0.03	0.55	0.49	0.03
	2	0.55			0.46		
	3	0.47			0.47		
Sahel 108	1	0.43	0.47	0.03	0.56	0.59	0.02
	2	0.44			0.61		
	3	0.53			0.61		

Appendix 10: Water input [mm irrigation and precipitation] for the ten varieties in the CPS and SSC over the cropping period; precipitation: 274.24 mm from 9-96 DAS)

	Crop duration mean	Water Input CPS	Crop duration CPS	mm day^{-1}	Water Input SSC	Crop duration SSC	mm day^{-1}
CG 14	85	669.24	84	7.97	638.63	86	7.43
Chomrong	76	814.98	76	10.72	604.17	76	7.95
IR 31785	88	689.96	85	8.12	604.30	90	6.71
IR 4630	110	864.72	109	7.93	724.75	110	6.59
IR 64	92	946.49	92	10.29	664.35	92	7.22
Jaya	102	933.28	101	9.24	627.90	102	6.16
Sahel 108	93	676.89	93	7.28	645.96	93	6.95
WAS 161	93	916.66	93	9.86	541.36	92	5.88
WAS 6322	85	712.18	84	8.48	616.34	86	7.17
Sahel 202	106	976.71	105	8.72	589.83	107	5.13

Appendix 11: Comparison of genotypic characteristics (xxx=high, xx=medium, x=low)

Trait		IR 31785	IR 4630	IR 64	Chomrong	CG 14	Sahel 202	Jaya	WAS 6322	WAS 161	Sahel 108
Duration (SD, MD, LD)		MD	LD	MD	SD	SD	LD	LD	SD	MD	MD
Plant development	early vigor		yes		yes			yes	yes	yes	yes
Water use in SSC	daily water input [mm]	xx	xx	x	x	x	xxx	xxx	x	xxx	xx
	water saving [mm day^{-1}]	xx	xx	x	xx	xxx	xxx	x	xxx	x	
	water prodcutivity [kg grain m^{-2} mm water input day^{-1}]	x	x	xx	xx	x	xxx	xx	x	xxx	xxx
Yield and Yield Components in SSC	yield [kg m^{-2}]	x	x	xxx	x	x	xxx	xx	xx	xxx	xx
	HI	xxx	x	x	x	x	xx	xxx	xxx	xx	xx
	Sterility [%]	xxx	xxx	xx	xxx	xxx	x	x	xx	x	xx

Curriculum vitae

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