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Rice-weed competition under upland and hydromorphic conditions in Ivory Coast

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Summary

The main aim of this study was to compare weed suppressing and yielding abilities of differing rice cultivars, in two hydrological zones and under two levels of Nitrogen availability. Special notice was given to cultivar V4, a promising cross between a well known weed suppressing Oryza glaberrima cultivar and a modern high yielding O. sativa cultivar.

The two hydrological zones were rainfed upland and the hydromorphic zone with groundwater available during the whole growing season. The hydromorphic areas are situated mostly in inland valleys and differ from year to year, depending on rainfall. Growing rice in this zone is interesting because rice can stand wet feet. In this study the response of these three different cultivars to weeds and fertilizer application were analyzed and compared with the results under upland conditions.

Performance of V4 was poor, it showed neither the weed suppressing capability of the traditional variety CG14 nor the high yielding quality of the modern semi dwarf variety WAB 56-104. Upland farmers, relying on hand weeding as the sole means of weed control, are suggested to grow CG14, if possible with a little N fertilizer. When it is possible to use herbicides or other means to keep the field weed free, modern high yielding cultivars can be chosen. In the hydromorphic zone there were no considerable differences between the tested cultivars or treatments. So in places that differ from year to year, recommendations for the upland zone hold for the hydromorphic zone as well.

1 Introduction

1.1 Background

At present the world population is still growing rapidly. The continent of Africa shows the highest growth figures, 3.0% annually (United Nations, 1990). A growth in agricultural production is necessary to feed this constantly growing population. In spite of this growing need for food, agricultural production per capita in Africa is staying constant or is even decreasing.

There are two possibilities to increase the agricultural production, 1) an increase in acreage and 2) an increase in production per hectare. The recent growth in rice production in West Africa is due to an increase in rice acreage (WARDA 1995). In West Africa there are still possibilities for a further increase in acreage. Especially the hydromorfic zones are suitable for wet-rice production but not used for agriculture at this moment (Andriesse *et al.*, 1994). These are mainly situated in inland valleys where groundwater is close to the surface or just above it, depending on time of the year and precipitation. In these hydromorphic areas the water level is not constant and rice is not flooded all the time. An increase of the production per hectare can be obtained in two ways. The first is to decrease the losses caused by diseases, pests and weeds. The second is by using more inputs, for example labour or fertilizers.

This study is about rice and weeds in West Africa. About rice because the people of West Africa eat more and more rice. This is partly due to urbanization. In comparison with the traditional staple foods, rice is easy to cook and easy to store. So rice is becoming a staple food for an increasing number of people, and the increase in the production of rice in West Africa lags behind. The region currently produces 64 % of its rice requirements and therefore imports from other countries, mostly from Asia. In the early 1990s nearly 3 million tons were imported annually, representing a total yearly cost of $800 million (Randolph, 1996). About weeds because weed competition is the most important yield-reducing factor for rice in West Africa (Dingkuhn *et al*, 1996).

In West Africa about half of the total rice acreage is free-draining upland rice. The average yield is as low as one ton of grain per hectare (Dingkuhn *et al.* 1996). The other half consists of irrigated lowlands, rice cultivated on hydromorphic valley fringes and rainfed lowlands. Yields are higher in these latter ecologies, but average yields in Africa are lower than anywhere else in the world (IRRI, 1995).

Farmers in Ivory Coast consider weeds as the biggest constraint to higher yields (Adesina & Johnson, 1993 en Adesina *et al.*, 1994). Arrandeau and Harahap (1986) found the same. Losses are caused by competition for water, light and nutrients. Losses in upland rice caused by weed competition can reach 100% (Akobundu & Fagade, 1978). Sahai *et al.* (1983) reported losses in India caused by weeds in upland rice up till 90%. The losses in lowland rice are lower (Akobundu, 1980). If the same field is used for rice production for many consecutive years, losses by weeds increase because of a gradual built up of the weed population.

It is clear that weeds are a major constraint for an increase in rice production of West Africa. If weeds can be controlled yields will rise considerably. Weeds can be controlled in many different ways, e.g. biological, preventive, cultural and chemical control and combinations (Akobundu, 1980). Most farmers in West Africa rely on preventive and cultural methods such as fallow periods between crops, hand weeding and tillage. Only 2% rely solely on the use of herbicides ; 24% of the rice farmers utilized herbicides in combination with hand weeding (Adesina & Johnson, 1993). The problem of hand weeding (mostly with a hoe) is that it costs a lot of time. And labor is the factor that limits the area that can be cultivated per farming household. Chemicals are often too expensive, not available or there is not enough knowledge to use them properly (Fofana *et al.*, 1995).

Other ways to reduce crop losses due to weeds are to improve tolerance or competitiveness of the rice plant by breeding. Weed-tolerance means that the crop does not suffer losses although there are weeds. Weeds don't affect the plant, or only a little. Competitiveness means that the crop is able to outcompete weeds for nutrients, water and light. The crop will suppress the weeds. Fofana *et al.* (1995) found that there is a negative correlation between both leaf area index and tiller number of rice during the vegetative phase and weed biomass at harvest. Garrity *et al.* (1992) reported the same results although he concluded that plant height was the factor most closely related to low weed biomass. Kawano *et al.* (1974) suggested that tiller number was not necessarily an important factor.

One of the activities of the West African Development Association (WARDA) is breeding rice. At WARDA breeders tried to combine the desirable qualities of the original African rice, *Oryza glaberrima* and a modern *Oryza sativa*. The *O.*

glaberrima has weed suppressing qualities based on vigorous early growth, high leaf area index, and prolific tillering. The most crucial weakness of *O. glaberrima* as a crop is low yield potential, resulting from its specific panicle type, tendency to lodge and to shatter grains (Dingkuhn *et al.* 1996). Besides the weed suppressing qualities, *O. glaberrima* cultivars are known for their resistance to drought, blast and other stresses. The modern *O. sativa* cultivars don't have most of these qualities but have a much higher yield potential.

In 1994, WARDA succeeded in breeding a viable cross. They crossed CG 14, a *O. glaberrima* cultivar, famous for its weed suppressing qualities, and WAB 56-104, a modern high yielding *O. sativa* cultivar with a japonica type (Fofana *et al.* 1995). The aim of this breeding effort was to develop a cross which in the early vegetative phase resembles the *O. glaberrima* and thus suppresses the weeds and that later performs like a modern *O. sativa* and thus produces a high yield.

It is important to know how this cross responds to higher nutrient input levels, because this is a determinant of higher yields per hectare. And weed suppressing varieties have the tendency to lodge when N is applied. So it is important to have a cultivar that is able to use the applied N effectively and doesn't lodge. Another aspect is how the additional nutrients will be distributed over rice and weeds. In earlier studies it was found that weeds capture most of the extra nutrients, causing even more weed problems (Boerema, 1963 and Johnson, unpublished data).

Another question is how the cross will perform in different ecologies. The *O. glaberrima* cultivars are mainly grown in upland ecologies. But as mentioned before there are also lowlands and hydromorphic valley fringes where rice can be grown. How will the cross react to a better water supply? And how will it react to different weed populations, since weed populations differ in different water regimes and cropping systems (Akobundu & Fagade, 1978, Gonzalez *et al.*, 1983, Smith, 1983)? Is the cross only superior in very specific ecological region or is it a cross that can be grown under different environmental conditions?

If the selected cross is found to contain the desirable qualities of both the *O. glaberrima* and *O. sativa* parent, it could mean a break through for the production of rice in West Africa. It would mean that acceptable yields will be possible in a situation where labour and money are limited.

1.2 Aim

The main aim of this study was to compare the weed suppressing abilities of a specific cross between *O. glaberrima* and *O.sativa* with those of the *O. glaberrima* parent and a much used *O.sativa* cultivar. As mentioned above, there are big expectations, but are they realistic? Another aim was to find how important early growth and early (and late) leaf area are.

The comparison was made under hydromorphic and upland conditions. In the hydromorphic zone, because there are possibilities of increasing the acreage of rice grown in these zones. It is important to determine whether this cross is suitable for zones like these, not in the least because of the specific weed populations and variable groundwater levels. Upland was chosen because of its importance for many small farmers who have problems with big losses caused by weed competition.

Another aim of this study was to test the response of the cross to application of nitrogen. This needs to be done because this is one of the most important ways to increase the production per hectare. A new cultivar needs to respond positively to extra nutrient application, because only if a combination of factors is used, it is to be expected that the rice production in West Africa will increase. The question is whether this new cross is able to use N efficiently? Therefore it is also important to study the ratio between uptake by rice and by weeds after applying additional N when grown in competition. Is the N-fertilizer used mainly by the crop or is it used by the weeds as was found in earlier studies with other cultivars?

2. Material and methods

In the wet season of 1996 an experiment was conducted at two experimental sites at WARDA headquarters in M'Be, Ivory Coast, to compare weed suppressing ability of three rice cultivars at two nitrogen application rates and at two positions along a toposequence of water availability. The two sites were next to each other on a slope. The upper part of the slope represented upland conditions, where the rice crop was completely dependent on rainfall as the only source of water. The lower part of the slope represented hydromorphic conditions. In this zone, groundwater was always available for the rice crop (never deeper than 20 cm below surface) and sometimes the rice field was even flooded because of the high groundwater level. The experiment was sown between 17-20 June 1996 at the beginning of the wet season.

2.1 Design

The experiment was laid out as a bi-location trial with a split plot randomized block design with three replications. The two locations were the upland and hydromorphic zones. All four combinations of weed pressure (weed free and single hand weeding at 28 Days After Sowing) and N-application rate (0 and 100 kg/m^2) were used as main plots. The three cultivars were in the sub plots (table 1). Originally there were five cultivars but due to time I only measured three cultivars. Plot size for the weed free treatment was 4*10 m, regardless of the N application rate. Hand weeded plots without additional N were 4*8 m and in the remaining 4*2 m N was applied. The two hand weeded plots were located next to each other. In former years, this was one main plot with one hand weeding without additional N. Just to have an indication what would happen after N application in the hand weeded plots, a strip of 2 m was fertilized.

2.2 Treatments

2.2.1 Cultivar

The three cultivars were CG 14, V4 and Moroberekan. CG 14 is an *Oryza glaberrima* cultivar with vigorous early growth and excessive leaf growth. *O.glaberimma* is

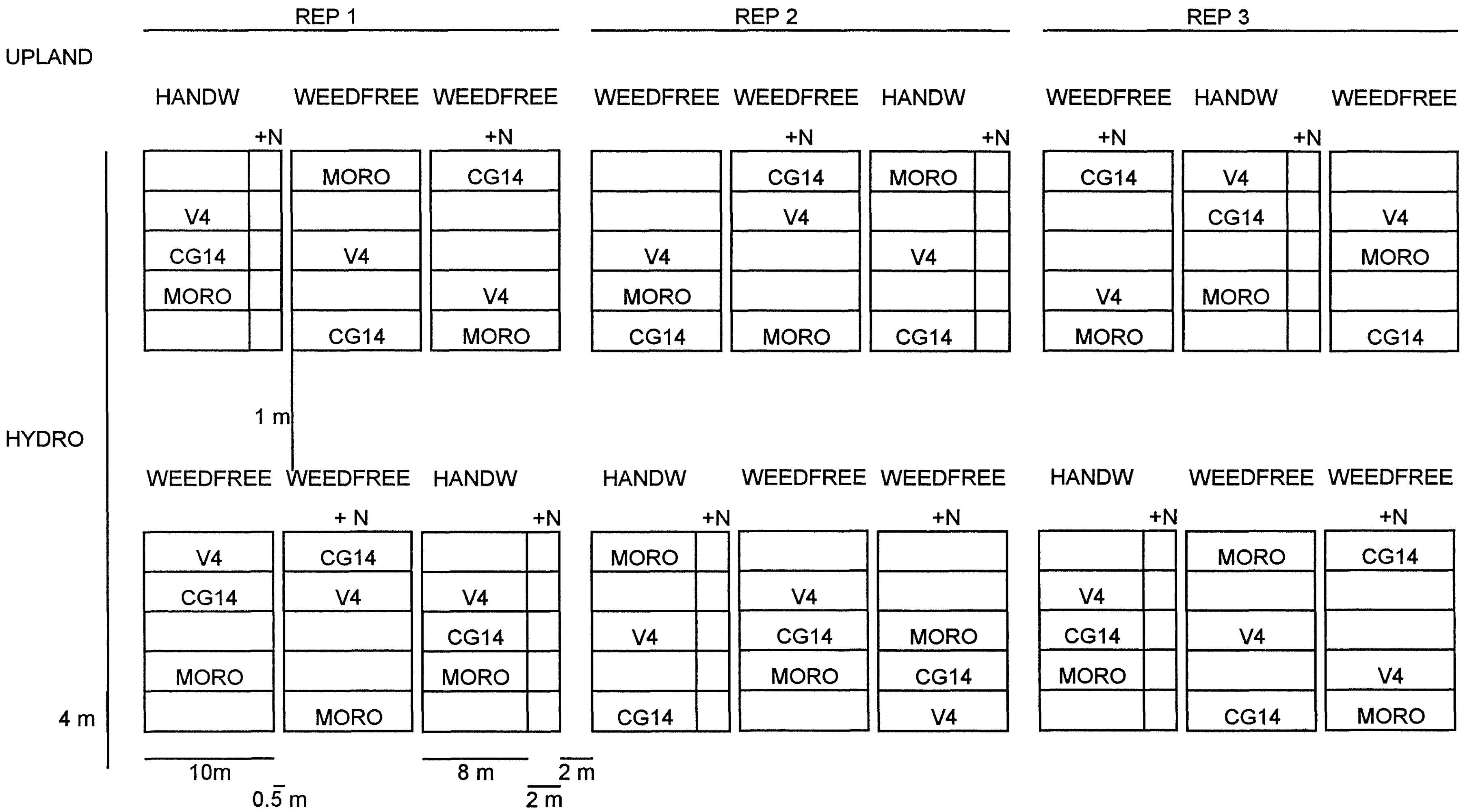


Table 1. Layout of the experiment. Two locations (upland and hydromopfic conditions), three replications, four main plots (combinations of weed pressure and N-application) and three sub plots (cultivars).

famous for its weed suppressing ability. V4 is a cross between CG 14 and a high yielding *O. sativa* cultivar (WAB 56-104). After preliminary tests this cross was expected to combine weed suppressing ability of the CG 14 and high yielding ability of the WAB 56-104. Moroberekan is a traditional *O. sativa,* with a long growing cycle compared to the other two cultivars. It is a low tillering cultivar with sturdy stems. Farmers like it because of its tolerance to weeds. Yields are not much affected when the crop is infested with weeds.

2.2.2 Weed pressure

There were two levels of weed pressure. The first level was a weed free crop, established through applying the herbicide Ronstar at 4 l/ha just before sowing. When necessary weeds were removed by hand to keep the plots free from weeds. The second level was a single hand weeding at 28 DAS (days after sowing). All weeds were removed by hand at that time, but weeds that emerged afterwards were left unharmed. No weeding at all was no option because of results in former experiments. Weeds outgrew the rice crop completely. So a single hand weeding was chosen as a minimal treatment.

2.2.3 Nitrogen

There were two levels of nitrogen. The first level was no nitrogen application and the second an application of 100 kg N/ha, applied as urea in two equal doses. The first half was applied at sowing, the second half was applied at 40 DAS. The reason for this split application of N was to increase the N uptake by the crop.

2.3 Management

The experimental sites were ploughed once to a depth of 20 cm and disk-harrowed twice, two weeks prior to sowing. The whole area received an application of 30 kg P (Triple Super Phosphate) and 100 kg K (KCl) before the second harrowing. Rice was sown at 7-10 seeds per hill with hill spacing of 25 *25 cm. After four weeks the hills were thinned to 5 seedlings per hill. There were no pest or disease control operations except for bird and rodent control.

2.4 Observations

Table 2. Observations at 28, 35, 42, 56,84 DAS and at harvest of shoot dry weight and paddy dry weight from rice and weeds and sample size.

Observations		28 DAS	35	42	56	84	harvest
Rice							
Shoot dry weight	4 hills			*	*	*	
Height	4 hills					*	
Paddy dry weight	6 m² or 2 m²						*
Weeds							
Shoot dry weight 0 N plots	1 m²	*					
Shoot dry weight	0,25 m²		*	*	*	*	*

Throughout the growing season shoot dry weight of the rice crops was determined (table 2). At 35,42 and 56 DAS shoot dry weight of 4 hills per plot was determined. For determination of dry weight, the plants were dried at 70°C for 36 to 48 hours. From 24 hours onwards dry weights were recorded every 12 hours. When weights didn't differ more than 1% the last weight was recorded.

At 84 DAS, shoot dry weight and height were determined. Height was determined along a vertical ruler. Harvested hills were held together at the base with one hand and the average length from base to panicle was recorded.

At harvest, paddy weight was determined. To be able to compare the results, moisture was subtracted to obtain dry paddy yield. In all plots 6 m² was harvested except for the hand weeded plots with additional N where 2 m² was harvested. This was because of the smaller plots (8 m² total)

Shoot dry weight of the weeds was determined at 28, 35, 42, 56, 84 DAS and at harvest. In each plot a 50*50 cm frame was randomly placed. All above ground parts of weeds were cut and dry weight was determined (70°C, 36-48 h.).

3 Results

3.1 Upland conditions

3.1.1 Rice growth till 84 Days After Sowing (DAS)

First the results till 84 DAS are presented, representing the vegetative growth. After this stage of development most of the assimilates produced are used for grainfilling. In figure 1 shoot dry matter production of the three cultivars is presented from 35 till 84 DAS under weed free and hand weeded conditions (means of 0 N and 100 kg N /ha levels). In figure 2 shoot dry weight between 35 and 84 DAS is presented comparing the two different N-levels (means of weed free and hand weeded plots).

At 35 and 42 DAS there was a cultivar effect (F pr. = 0.005 and 0.001 resp.). At 35 DAS shoot dry weight of CG14 was larger than shoot dry weight of V4 and Moroberekan. At 42 DAS shoot dry weight of CG14 and V4 was larger than the shoot dry weight of Moroberekan. At 56 DAS there were Weeding*Cultivar and Nitrogen*Cultivar interaction effects (F pr. =0.003 and 0.010). Moroberekan did not show any difference in the weed free vs. the hand weeded plots. V4 and CG14 responded with an increased shoot dry weight to clean weeding. The same was valid for the N fertilization, V4 and CG14 responded with an increased shoot dry weight, whereas Moroberekan did not respond. At 84 DAS there were only significant weeding and nitrogen effects (table 3). In weed free plots the shoot dry weight was larger than in the hand weeded plots and all cultivars responded positively to N fertilization. At 35, 42 and 84 DAS there were no interactions between weed treatment and N-application.

However, besides the statistical analysis there were some trends. Looking at the graph (figure 1) two groups can be distinguished: 1) V4 and CG14, weed free and 2) V4 and CG14 hand weeded and Moroberekan both weed free and hand weeded. Similar results were found for height at 84 DAS (table 4). Height of Moroberekan was 105 cm in both weed free and hand weeded conditions, height of V4 and CG14 was reduced from 115 to 100 cm due to the presence of weeds.

Table 3. Effect of weed treatment (weed free vs. one hand weeding at 28 DAS) and N fertilization (0 vs. 100 kg urea/ha) on above ground (shoot) dry matter(g/m^2) at 84 DAS of three rice cultivars (Moroberekan, V4 and CG14) and weeds grown under upland conditions.

	Weed free		Average	Hand weeded		Average	Weeds	
	0N	+N		0N	+N		0N	+N
Moroberekan	256	530	393	226	338	282	81	59
V4	669	718	693	148	415	282	48	67
CG14	617	691	654	216	498	356	27	19
Average	511	646		195	417		52	48
Average	579			306		Without rice	104	174

Standard errors of differences of means of rice

sed weed treatment (W)	44.00	P=<0.001	sed nitrogen (N)	44.00	P=0.007
sed cultivars (C)	79.84	P=0.107	sed W * N	62.24	P=0.361
sed W * C	102.20	P=0.198	sed N * C	102.20	P=0.974
sed W * N * C	144.52	P=0.423			

except when comparing means with same level(s) of W sed=112.9, N sed=112.9, W*N sed=159.7
lsd of weeds at 0,5 alpha level was 79

Table 4. Effect of weed treatment (weed free vs. one hand weeding at 28 DAS) and N fertilization (0 vs. 100 kg urea/ha) on height at 84 DAS (cm) of three rice cultivars (Moroberekan, V4 and CG14) grown under upland conditions.

	Weed free		Average	Hand weeded		Average	Average	
	0N	+N		0N	+N		0N	+N
Moroberekan	100	115	105	95	115	105	95	115
V4	110	120	115	85	105	95	100	115
CG14	110	120	115	85	120	100	100	120

Standard errors of differences of means

sed weed treatment (W)	4.30	P=0.041	sed nitrogen (N)	4.30	P=0.005
sed cultivars (C)	3.00	P=0.345	sed W * N	6.08	P=0.200
sed W * C	5.52	P=0.048	sed N * C	5.52	P=0.686
sed W * N * C	7.81	P=0.425			

except when comparing means with same level(s) of W sed=4.24, N sed=4.24, W*N sed=6.0

For each cultivar, N-application resulted in a positive effect on the shoot dry weight during the vegetative period. But looking at figure 2, three categories can be seen: 1) Moroberekan without N application (about 240 g/m^2). 2) Moroberekan with

Figure 1. Shoot dry weight from 35 till 84 DAS under weed free and hand weeded conditions in upland (average of 0N and 100 kg urea/ha plots).

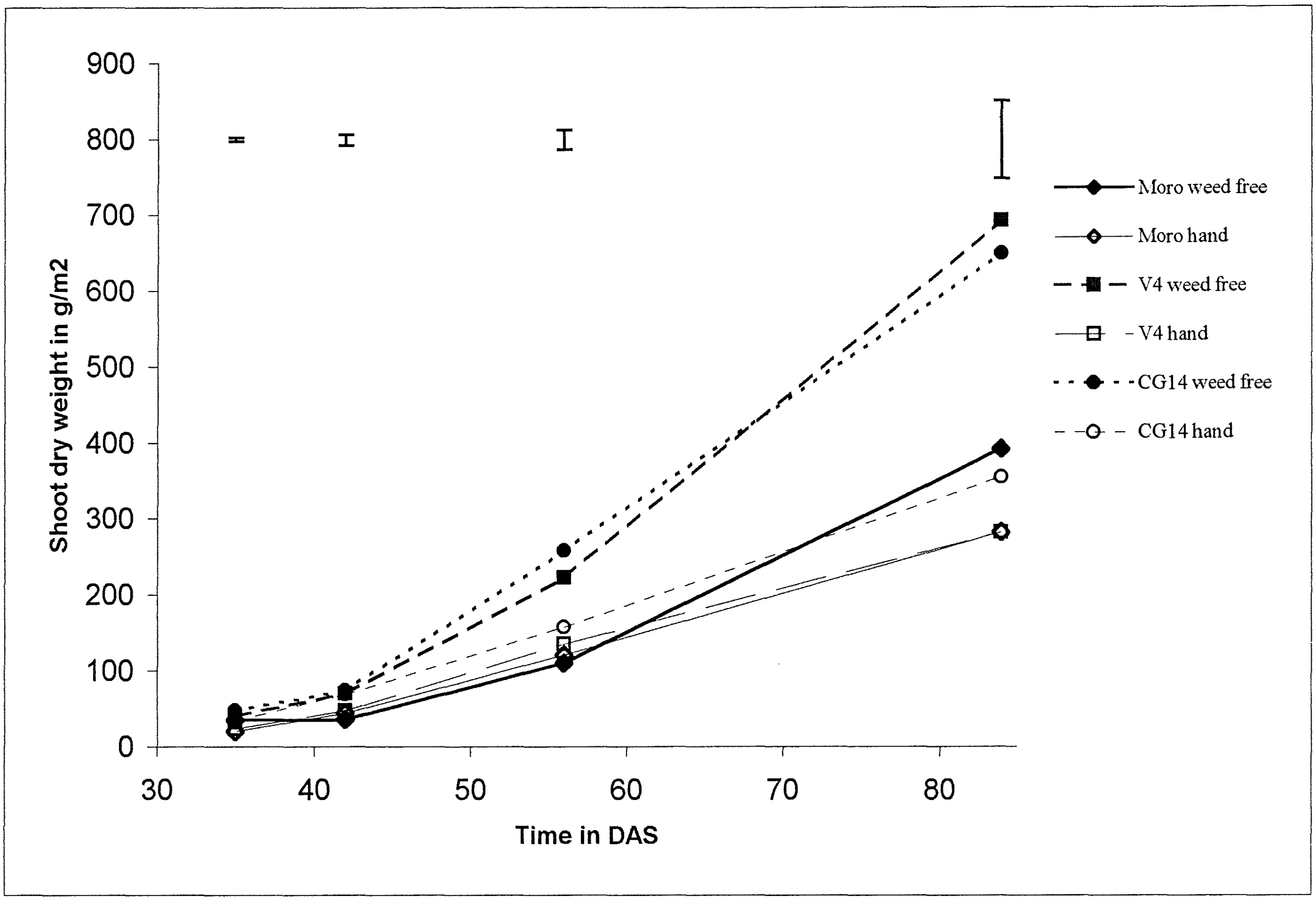
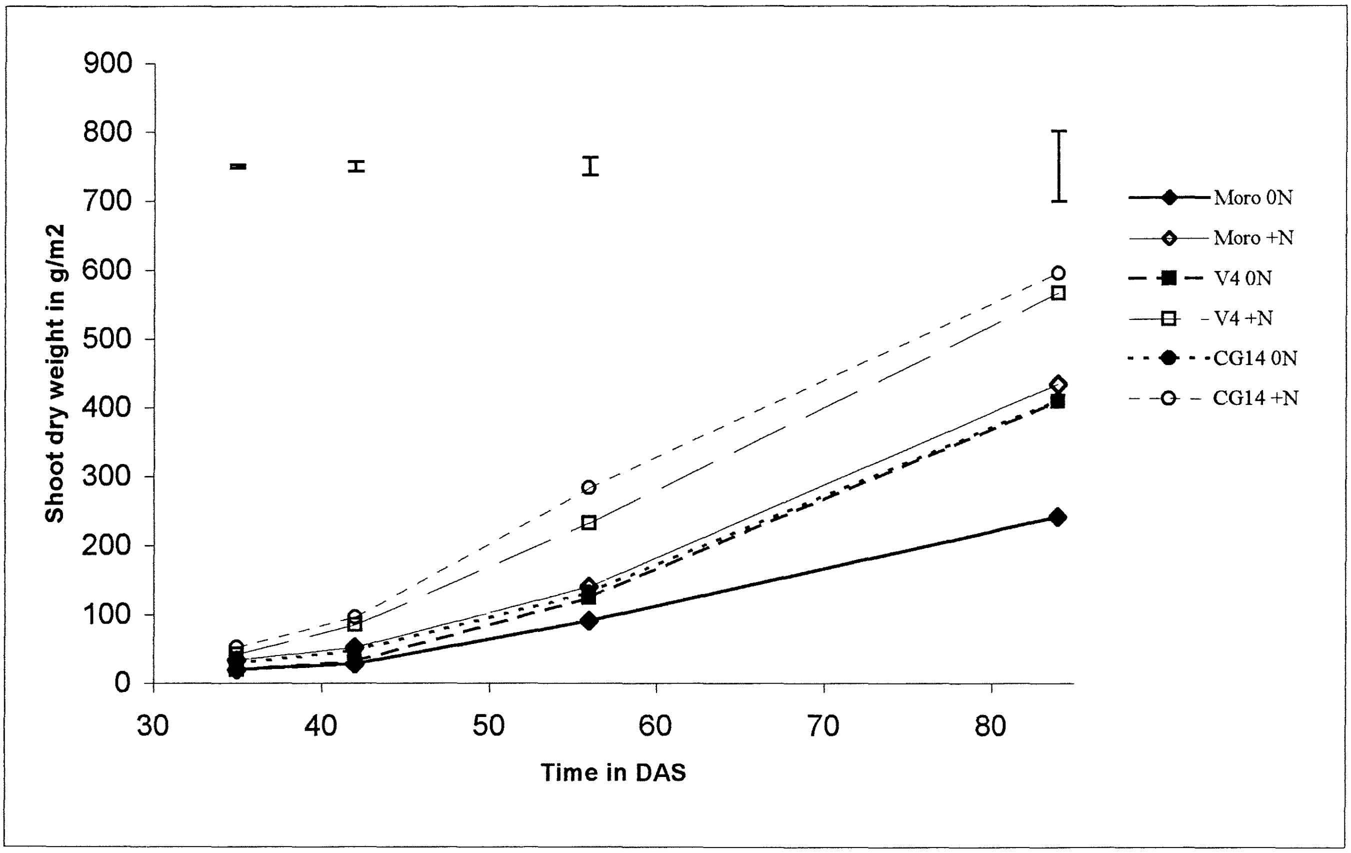


Figure 2. Shoot dry weight from 35 till 84 DAS under 0N and 100 kg urae/ha conditions in upland (average of weed free and hand weeded plots).



additional N and V4 and CG14 without N-application (about 420 g/m²). And 3) V4 and CG14 with N fertilization (about 580 g/m²).

In weed free plots Moroberekan showed the highest response to extra N, more than two times as much DM (from 255 to 530 g/m², but 255 was very low). Under hand weeded conditions V4 and CG14 used the N better, DM increased from 180 to 455 g/m², while DM of Moroberekan increased from 225 to 340 g/m². In hand weeded plots, weed biomass did not differ between plots of the three cultivars up to 84 DAS, irrespective of N-application.

Weed biomass in the different plots didn't show any treatment effects. Of weeds removed at 28 DAS, weights are only available for the 0 N plots. Again no clear treatment effects are observed. For Moroberekan and CG14 72 g/m² and for V4 92 g/m² of weed DM was found. The differences between the DM of rice in the weed free plots and the hand weeded ones are not explained by weed growth. In the 0N plots DM of Moroberekan, DM weeds at 28 DAS and 84 DAS equals 379 g/m². This is more than the 256 grams in the weed free Moroberekan plots. For V4 and CG14 the opposite was observed. Here the weed free plots produced the higher total DM, 669 and 617 grams in weed free plots against 288 and 315 grams in the hand weeded plots of V4 and CG14 respectively. The same calculations cannot be made for the +N plots as weed biomass data at 28 DAS are lacking.

3.1.2 Final harvest

In table 5 paddy yields at harvest are presented. Cultivars V4 and CG14 were harvested 112 DAS. Moroberekan matured about one week later and was harvested at 119 DAS. The three way interaction W*N*C was significant. Because of the three way interaction it is not possible to look at the yields the same way as at the dry matter up till 84 DAS. Under weed free conditions and without N fertilization, yields of V4 and CG14 were identical at about 325 g/m². Yield of Moroberekan was statistically lower ($\alpha = 0.10$) with 170 g/m². When additional N was applied in the weed free plots, lodging occurred in cultivar CG14. Consequently, yield of CG14 decreased significantly to a level of 175 g/m². Yield of Moroberekan and V4 increased as a result of the N-application, and the difference between both cultivars was no longer significant ($\alpha > 0.10$).

When weed control was limited to one hand weeding at 28 DAS, average yield of all cultivars at 0 N decreased significantly from 275 g/m^2 to 170 g/m^2. There were no differences in yield between cultivars. When N was applied in plots with a single hand weeding, average yield of all cultivars increased significantly from 170 to 280 g/m^2. Under these conditions, yield of CG14 was significantly higher than yield of Moroberekan and V4. If yield of all cultivars at high N are compared for weed free and hand weeded conditions, remarkable differences are found. For Moroberekan and V4 yields were significantly lower under hand weeded conditions. For CG14, yield under hand weeded conditions was significantly higher. Unlike in weed free plots, no lodging of CG14 was observed when plots were only weeded once (hand weeded).

Because of this different behavior of CG14 (lodging) in weed free plots with N fertilizer, a contrast analysis was made between Moroberekan and V4 at the one hand and CG14 at the other. Moroberekan and V4 responded alike to all treatments and differed from CG14 (table 5).

Regrowth of weeds (figure 5) after the one hand weeding at 28 DAS showed no differences till harvest. At harvest an interaction between cultivar and additional N (α=0.10) appeared. In 0 N plots V4 had a larger weed dry biomass than Moroberekan and CG14 (170 vs. 95 g/m^2). In fertilized plots Moroberekan and V4 had a larger weed dry biomass than CG14 (140 vs. 45 g/m^2).

Table 5. Effect of weed treatment (weed free vs. one hand weeding at 28 DAS) and nitrogen application (0 and 100 kg urea/ha) on the yield (paddy dry weight g/m2) of three rice cultivars (Moroberekan, V4 and CG14) grown under upland conditions.

	Weed free		Hand weeded		
	0N	+N	0N	+N	Average
Moroberekan	171	429	129	237	242
V4	322	528	145	209	301
CG14	327	176	236	388	282
Average	273	377	170	278	
Average	325		224		

Standard errors of differences of means

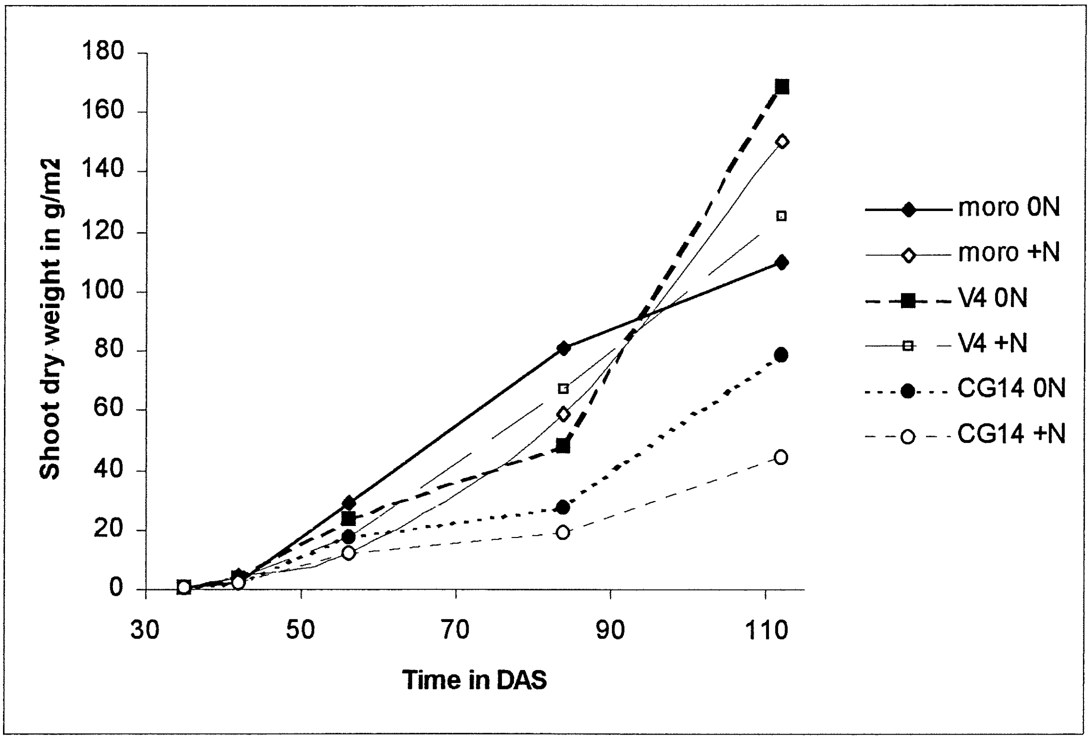
sed weed treatment (W)	18.87	P=0.002	sed Nitrogen (N)	18.87	P=0.001
sed cultivars (C)	40.07	P=0.345	sed W * N	26.69	P=0.924
sed W * C	49.96	P=0.005	sed N * C	49.96	P=0.092
sed W * N * C	70.66	P=0.018			

except when comparing means with same level(s) of W sed=56.66, N sed=56.66, W*Nsed=80.13

Contrast analysis B*W*N*C Stratum

sed C	Others vs CG14	P=0.765	Moroberekan vs V4	P=0.159
sed W*C	Others vs CG14	P=0.003	Moroberekan vs V4	P=0.120
sed N*C	Others vs CG14	P=0.036	Moroberekan vs V4	P=0.558
sed W*N*C	Others vs CG14	P=0.005	Moroberekan vs V4	P=0.956

Figure 5. Shoot dry weight of weeds (regrowth) from 35 DAS till harvest in hand weeded plots under upland conditions.



3.2 Hydromorphic conditions

3.2.1 Rice growth till 84 DAS

Table 6. Effect of weed treatment (weed free vs. one hand weeding at 28 DAS) and nitrogen application (0 vs. 100 kg urea/ha) on the above ground dry matter (g/m²) at 84 DAS of three rice cultivars (Moroberekan, V4 and CG14) and weeds under hydromorfic conditions.

	Weed free		Hand weeded			Weeds	
	0N	+N	0N	+N	Average	0N	+N
Moroberekan	388	296	301	553	384	65	38
V4	410	501	294	455	415	60	52
CG 14	406	610	316	304	409	18	17
Average	401	469	304	438		48	37
Average	435		370		Without rice	89	131

Standard errors of differences of means of rice

sed weed treatment (W)	44.48	P=0.197
sed nitrogen (N)	44.48	P=0.064
sed cultivars (C)	49.96	P=0.816
sed W * N	62.88	P=0.486
sed W * C	72.84	P=0.045
sed N * C	72.84	P=0.899
sed W * N * C	103.0	P=0.049

except when comparing means with same level(s) of W sed=70.64, N sed=70.64, W*N sed=99.88
lsd of weeds at 0,5 alpha level was 67.

There were no big differences between the cultivars, the weeding treatment and N-application till 56 DAS (figure 6). At 84 DAS there was a three way interaction between these three factors (P=0.049). Under 0 N conditions there were no cultivar differences in above ground dry matter whether weed free or hand weeded. N-application had a positive effect on Moroberekan and V4 under hand weeded conditions, but not under weed free conditions. CG14 behaved differently, under hand weeded conditions there was no difference between 0N and fertilized plots. Under weed free conditions though there was a positive effect to N-application.

Under fertilized conditions Moroberekan behaved differently from V4 and CG14. Shoot dry weight of Moroberekan was lower under weed free conditions than

Figure 6. Shoot dry weight from 35 till 84 DAS under weed free and hand weeded conditions in hydromorphic zone (average of 0N and 100 kg urea/ha plots).

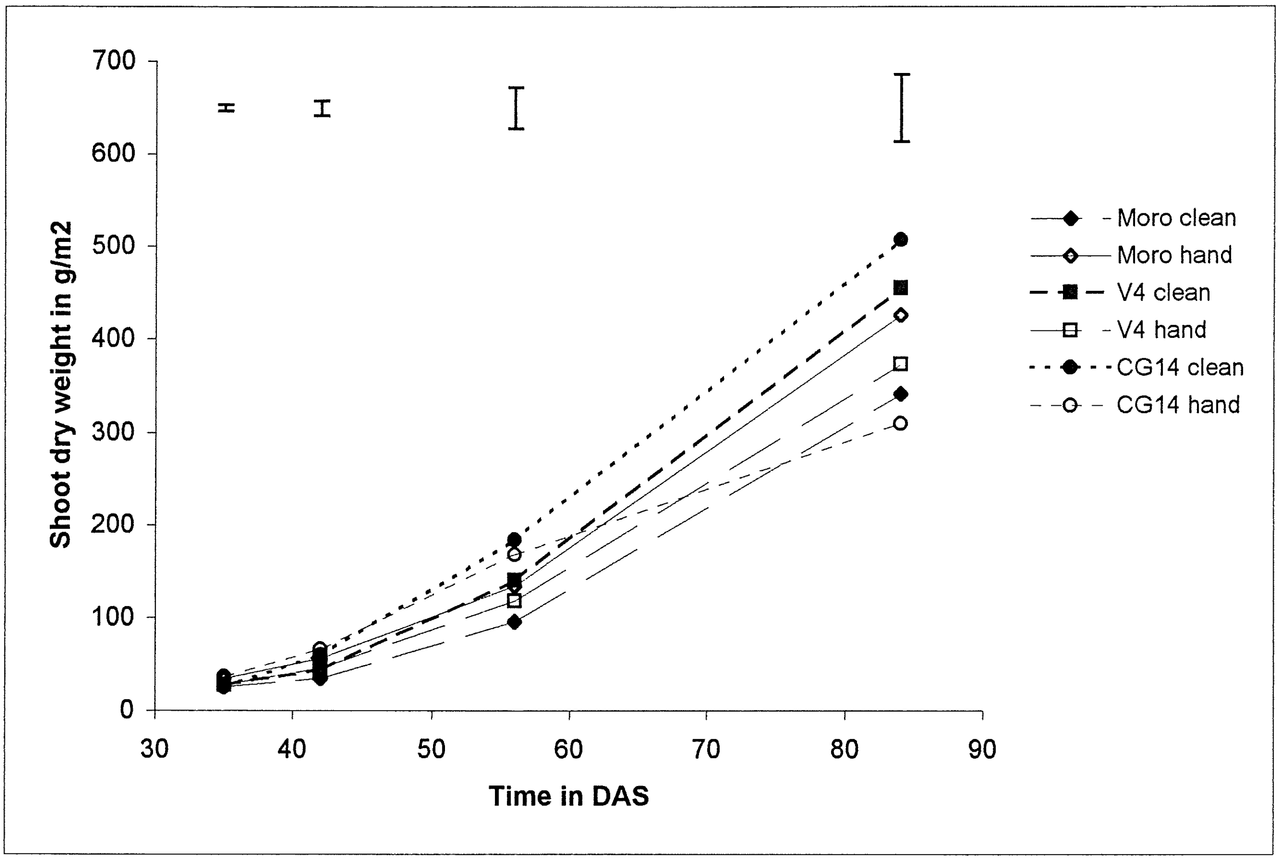
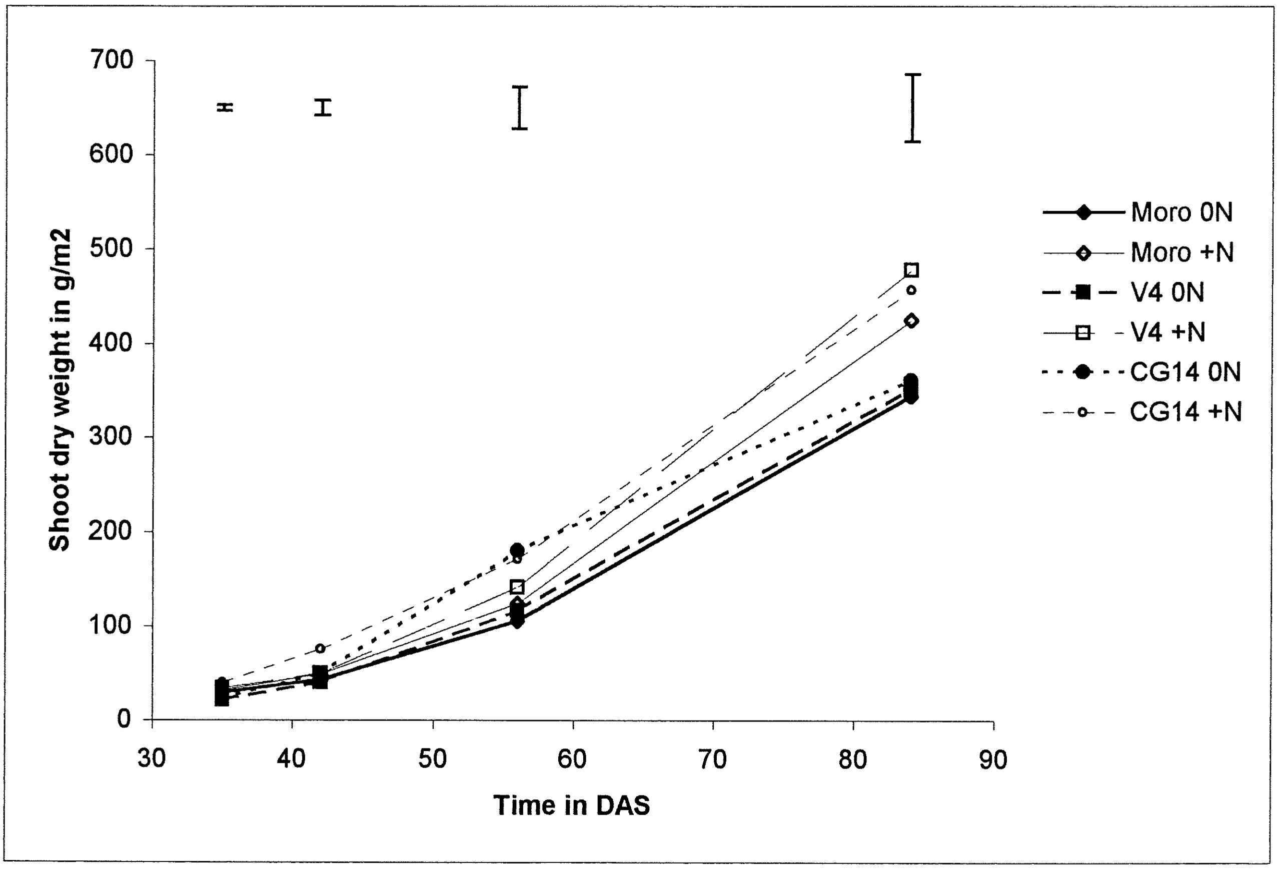


Figure 7. Shoot dry weight from 35 till 84 DAS under 0N and 100 kg urea/ha conditions in hydromorphic zone (average of weed free and hand weeded plots)



under hand weeded conditions. CG14 had higher shoot dry weight under clean weeded conditions and V4 had the same shoot dry weight.

The differences between Moroberekan and V4 in their response to N-application and weeding treatment showed the same trend at 56 DAS (figure 6).

The results found under upland conditions with weed regrowth were also found under hydromorphic conditions. Total DM of Moroberekan, weeds removed at 28 DAS and weeds harvested at 84 DAS was almost equal to the DM of rice in the weed free plots (406 versus 388 grams). V4 and CG14 obtained a higher total DM in the weed free plots than in the hand weeded plots, 410 vs. 312 and 406 vs. 346 resp. Here also the data on weed biomass at 28 DASare lacking on the + N plots.

3.2.2 Final harvest

The dry matter differences at 84 DAS were not translated into differences in paddy production (table 7). At harvest there was only an effect of weeding treatment in the hydromorphic zone. The weed free plots yielded more paddy than the hand weeded plots. Only the order of magnitude differed between cultivars. In the Moroberekan plots the difference between weed free and hand weeding was marginal. Dry paddy yield of V4 and CG14 in clean weeded plots was on average 105 g/m^2 higher than in hand weeded plots.

When average paddy yield of all treatments under upland conditions were compared to yields under hydromorphic conditions, there are two main differences between the two zones. First, although CG14 also lodged in the hydromorphic zone under weed free conditions with N-application, paddy yield was not affected. Lodging in the hydromorphic zone started later and was less massive, though.

The second was that Moroberekan behaved differently under weed free conditions in response to N-application. Under upland conditions there was a large positive response, yield more than doubled. Under hydromorphic conditions there was no difference between 0N and fertilized plots. For the other cultivars and treatments yields were quite comparable.

Table 7. Effect of weed treatment (weed free vs. one hand weeding at 28 DAS) and nitrogen application (0 vs. 100 kg urea/ha) on the yield (paddy dry weight g/m²) of three rice cultivars (Moroberekan, V4 and CG14) in hydromorfic conditions.

	Weed free		Hand weeded		
	0N	+N	0N	+N	Average
Moroberekan	241	279	241	274	259
V4	263	306	207	184	240
CG 14	273	396	206	214	272
Average	259	327	218	224	
Average	293		221		

Standard errors of differences of means

sed weed treatment (W)	27.93	P=0.042
sed nitrogen (N)	27.93	P=0.236
sed cultivars (C)	29.47	P=0.558
sed W * N	39.51	P=0.308
sed W * C	44.02	P=0.136
sed N * C	44.02	P=0.656
sed W * N * C	62.26	P=0.657

except when comparing means with same level(s) of W sed=41.67, N sed=41.67, W*N sed=58.94

4 Discussion & conclusions

The experiment with three cultivars, two levels of weed pressure and two hydromorphic zones was conducted to examine the weed suppressing and yielding characteristics from a new cultivar, V4, in two different ecological zones. This V4 is a cross between CG14, a strong weed suppressing cultivar and WAB 56-104, a high yielding cultivar. CG14 and Moroberekan were the other two cultivars used in the experiment.

Although the results show that there are differences between treatments, the standard errors are quite large. These large standard errors can partly be explained by the following:

-Irregular thinning. Four weeks after sowing all hills should have been thinned to five plants per hill. However, at thinning, plants were taken from all hills, rather than reducing density to 5 plants/hill. It happened that hills of 30 plants were thinned to 15 plants and hills of 10 plants to 5 plants. Therefore already at the start of the experiment there were large differences in tiller and plant number between hills.

Especially between hills of different treatments. Within subplots sowing density and stand density after thinning was uniform.

-Places of sampling. Samples till 42 DAS were taken near the edge of the field. From 56 DAS onwards samples were taken randomly. Samples were also taken from the area reserved for final harvest. Especially for the plots where only 2 m^2 was available for the final harvest, this might have had a considerable effect on results of the final harvest.

4.1 Upland conditions

Our results confirm the importance of weeds as a constraint to higher yields. Moroberekan suffered a 40 % yield reduction due to weeds (300 vs. 183) V4 even responded to weeds with a 60% yield reduction (425 vs. 177). CG14 without N application showed a trend towards yield reduction due to weeds. With application of N, this cultivar lodged in weed free plots whereas it didn't lodge in hand weeded plots. Because of this lodging, yields between weed free and hand weeded plots under fertilized conditions were not different. The potential effect of weeds on CG14 when no lodging would have occurred, can be derived from the data at 84 DAS when a 45% reduction in DM was observed. It is likely that CG14 is sensitive to lodging whenever it is grown in very favourable conditions. The difference between hand and clean weeding started early. Already at 35 and 42 DAS there were differences in rice DM between these two conditions although at that time there were almost no weeds. This was irrespective of cultivar. This implies an effect from weeds that grew till the hand weeding at 28 DAS.

It is remarkable that the total biomass of rice and weeds is not comparable between the hand weeded and weed free plots. Maybe light was not the limiting factor, N possibly was. To roughly estimate N-uptake in the hand weeded and weed free treatments we assume a 0,8 % N content in the rice (50% heading) as suggested by Bufogle *et al.*(1997). The difference in N-uptake would be accounted for by the weeds which would have a N content of approximately 4%. Since more than half of the weeds was young when removed at 28 DAS, this seems quite possible. This explanation only doesn't hold for Moroberekan, but does hold for V4 and CG14 under both upland and hydromorphic conditions. In the West-African context a competitive rice cultivar should be competitive in N-uptake according to this conclusion. Further research is needed with more focus on N-uptake by weeds and rice crop to understand the functioning of the rice-weed system.

Under hand weeded conditions CG14, profited from N-application and responded with a higher yield whereas Moroberekan and V4 didn't. It seems that in plots with Moroberekan and V4 the N fertilizer was used by the weeds and in plots with CG14 by the rice crop. Under clean weeded conditions, Moroberekan and V4 responded positively to N-application in contradiction to CG14. CG14 lodged and therefore gave a lower yield. From the earlier samples it is obvious that CG14 responded positive to N-application until it lodged. The stems of Moroberekan and V4 were sturdier and thicker in comparison with the stems of CG14. As a result, CG14 obtained its highest yield under hand weeded conditions with N-application and not under clean weeded conditions. Moroberekan and V4 obtained their highest yield under clean weeded conditions with N-application.

N-application did not have an effect on the weed regrowth after the single hand weeding at 28 DAS. Weed didn't grow better or worse with or without N-application. But there was an interaction at harvest between N-application and cultivar (α=0,10). In plots with Moroberekan and V4, 3 times more weeds were found at harvest time than in CG14 plots when N was applied.

Looking at the yield results under hand weeding, CG14 yielded best. The yield was 170% of the average yield of Moroberekan and V4. And the weed biomass in CG14 plots was less than 50% of the weed biomass in the Moroberekan and V4 plots. So it can be concluded that CG14 was less affected by weed growth and suppressed weed growth better than the other two cultivars. Dry weight and height of the crops did not differ between the cultivars until 84 DAS. So a better suppression of weeds did correspond with a higher yield, but did not correspond with a higher DM or height at flowering.

Under clean weeded conditions yield of V4 was higher than yields of Moroberekan and CG14. Highest yields were obtained by V4 and Moroberekan with N application. To obtain a high yield, CG14 was not a suitable cultivar. But to obtain the highest yield under conditions with weed pressure, CG14 looks the better cultivar of the three.

Moroberekan responded like a traditional *Oryza sativa*. Under sub-optimal conditions (no N-application) it yielded comparable under hand weeded and under clean weeded conditions. The weeds did not affect Moroberekan very much, an example of weed tolerance, no losses even though there are weeds. With N fertilizer, weeds had a bigger influence. The biomass of the weeds however was not higher in plots with additional N.

CG14 fulfilled the expectations. It was a leafy crop with many tillers, and as a result suppressed the weeds best. On the other hand, it was the only cultivar with difficulties with higher N input levels. For a good performance this cultivar needs an environment where N is applied in restricted amounts, since the crop is susceptible to lodging.

V4 did not fulfil the expectations. It did not yield better under weed free conditions with additional N than Moroberekan, a traditional rice cultivar. So, the high yielding capacity from the modern *O. sativa* parent does not seem to be present. The weed suppressing capabilities from the other parent, CG14, were not found either. In V4 plots a higher weed biomass was found than in CG14 plots, both with and without N-application. Compared to plots with Moroberekan there was no difference in weed growth. Qualities that are associated with weed suppression like tall stature, quick establishment and leaf growth or a high number of tillers were not observed.

When a farmer relies on hand weeding as the sole means of weedcontrol, CG14 is the best cultivar to choose from these three. When available, a little N can be applied to raise the yield considerably. N-application has to be very moderate though to prevent lodging. For clean weeded conditions there might be better cultivars like modern *O. sativa* types.

4.2 Hydromorphic conditions

Under hydromorphic conditions rice yield also suffered from weeds. On average 15% at 0 N and 30% with N fertilizer. There was no cultivar effect, N effect or interaction effects.

Just as under upland conditions, CG14 lodged in the hydromorphic zone when clean weeded and when N was applied, but at a later stage during grain filling. The grains had already had some time to fill before the crop lodged. This explains why there is no difference in response to N fertilization between Moroberekan and V4 on the one hand and CG14 on the other like under upland conditions.

The reason that there are no N effects can be the wet environment in which the crop was grown. It is possible that the applied urea behaved differently in this wet environment than under dry upland conditions. Urea ($CO(NH_2)^2$) hydrolyses with H_2O to $2NH_3 + CO_2 + H_2O$. NH_3 is volatile. Than NH_3 reacts with O_2 to $H^+ + NO_3^- +$ H_2O. Under anaerobic conditions NO^-_3 can be reduced to NH_3, N_2O or N_2, all being volatile. Another explanation might be that the soluble N was washed away during a storm which occurred directly after the N application.

For a farmer who has his field in a hydromorphic zone it does not matter much which cultivar he grows. When he relies only on hand weeding, urea application is no use given the present results. Under clean weeded conditions application of urea might have some positive effect on CG14.

But every year, depending on rainfall, the border of the hydromorphic zone to with upland zone is different. So where one year there are upland conditions, the following year it is possible that there are hydromorphic conditions. Since yields under hydromorphic conditions did not differ between cultivars, it is wise to follow the recommendations for upland conditions when there is a possibility that the crop might be dependent on rainfall as sole water supply.

N-application may than be restricted to the expected upland zone given actual hydrology and rainfall patterns at the moment of N-application.

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Data Rice Upland

		DM 35 DAS (in grams/0.25 m²)	DM 42 DAS	DM 56 DAS	DM 84 DAS	DM paddy yield (in grams/m²)
Weed free +N						
	rep					
Moro	1	11,3	12,3	36,9	114,4	697,9
Moro	2	10,3	10,6	39,3	88	271,5
Moro	3	10,3	8,7	27,7	194,9	318,6
V4	1	14,4	16,3	60,5	141,2	430
V4	2	10,6	38,6	76	226,2	597,8
V4	3	14,4	21,1	72,7	170,8	555,1
CG14	1	12,2	22,4	93,3	208,2	218,9
CG14	2	17,5	28,2	81,2	258,1	106,1
CG14	3	12,4	23,6	76,3	52,2	202,7
Weed free 0 N						
	rep					
Moro	1	4,9	4	10,8		166,1
Moro	2	6,2	6,3	16,4	45,6	162,1
Moro	3	9,2	12,1	34,8	61	184,4
V4	1	7,8	10,3	46,7	162,8	357,9
V4	2	5,6	6,4	36,1	143,6	274,9
V4	3	7,4	12,1	41,3	195,4	333,4
CG14	1	9	4,6	41,3	199,5	318,5
CG14	2	11,4	17,4	39,2	149,2	324,6
CG14	3	8	15,3	55	107,9	337,8
Hand weeded +N						
	rep					
Moro	1	7,9	21,7	43	137,2	328,1
Moro	2	6,1	17,2	43,3	64,6	266,1
Moro	3	4,3	7,5	20,3	51,9	117,7
V4	1	6,1	20,6	53,6	122	194,5
V4	2	10,2	18	51,3	117,7	128,7
V4	3	6,4	12,5	34,4	71,7	303,5
CG14	1	15,5	31,1	83,7	146,3	416,6
CG14	2	9,9	22,5	38,9	102	405,6
CG14	3	10,3	16,4	50,7	125,3	341,9
Hand weeded 0N						
	rep					
Moro	1	5,4	11,1	29,8	76,3	198,9
Moro	2	2,9	6	28	64,6	137,8
Moro	3	1,8	2,4	16,8	29	51,48
V4	1	4,9	6,5	24,9	50,7	141,2
V4	2	3,3	7,3	23	46,7	148
V4	3	3	5,3	14,8	13,5	144,3
CG14	1	5,8	17,8	32,5	87,4	240,2
CG14	2	6	12,7	17,3	39,31	265,9
CG14	3	2,7	3,3	11,9	31,9	202,6

Data rice upland

grams/0.25 m²

		Total DM harvest	Leaf dry weight	panicle dry weight	stem dry weight
Weed free +N					
	rep				
Moro	1	445,3	80,3	178,5	186,5
Moro	2	275,9	53,6	102,7	119,6
Moro	3	202,5	38,5	68,4	95,6
V4	1	355,8	43,1	175,7	137
V4	2	338	43,8	169,7	124,5
V4	3	232,9	31,9	107	94
CG14	1	229,3	41,6	73,4	114,3
CG14	2	157,3	38,8	45,8	72,7
CG14	3	208,7	42,7	47,1	118,9
Weed free 0N					
	rep				
Moro	1				
Moro	2	139,5	26,9	47,1	65,5
Moro	3	142,2	22,8	30,1	89,3
V4	1	217,9	31,4	107,6	78,9
V4	2	189	29,2	95	64,8
V4	3	127,7	17,2	61	49,5
CG14	1	271	36,9	124	110,1
CG14	2	269,8	42	132	95,8
CG14	3	194,1	28	89,5	76,6
Hand weeded +N					
	rep				
Moro	1				
Moro	2				
Moro	3				
V4	1				
V4	2				
V4	3				
CG14	1				
CG14	2				
CG14	3				
Hand weeded 0N					
	rep				
Moro	1	208,1	35,9	78,8	93,4
Moro	2	179,2	34,4	72,5	72,3
Moro	3	31,5	6,9	8,3	16,3
V4	1	117,5	16,9	58,2	42,4
V4	2	83	13,4	39,1	30,5
V4	3	32,1	5,7	14	12,4
CG14	1	159,2	22,4	75,5	61,3
CG14	2	162,5	26,7	75,7	60,1
CG14	3	83,4	11,6	40,9	30,9

Data rice hydromorphic zone

in grams/0,25 m² (DM 28 DAS – DM 84 DAS); in grams/m² (DM paddy yield)

	rep	DM 28 DAS	DM 35 DAS	DM 42 DAS	DM 56 DAS	DM 84 DAS	DM paddy yield
Weed free + N							
Moro	1						326,55
Moro	2	2,8	5,6	8	22,5	100,1	201,63
Moro	3	2,9	5,8	11,2	25,2	69,9	460,55
V4	1	2,7	8,2	9,3	36,1	123,5	409,33
V4	2	2,1	4,1	7	40,4	155,7	320,88
V4	3	2,6	10,4	18,2	31,4	96,3	405,08
CG14	1	4,1	8,2	12,7	39,8	110,7	544,68
CG14	2	2,1	4,5	8,7	22,9	126,9	564,98
CG14	3	3	14,8	40	86,7	219,8	351,67
Weed free 0N							
Moro	1	3,4	7,4	13,1	34,6	113,3	240,97
Moro	2	2,6	7,5	7	21,1	77,2	344,33
Moro	3	4,7	7	11,6	24,3	100,1	279,5
V4	1	2,1	4,9	8,7	33,5	87,9	215,78
V4	2	2	7,4	10,6	32	103	408,13
V4	3	3,1	6,3	11,5	36,1	116,8	340,33
CG14	1	2,2	4,6	6	19,6	88,8	293,72
CG14	2	1,5	3,7	8	16,8	66,7	342,38
CG14	3	3,4	4	15	89,7	148,7	355,98
Hand weeded +N							
Moro	1			20,7	36,5	147,6	268,25
Moro	2		10,5	16,1	40,8	106,7	363,8
Moro	3						311,6
V4	1		10,8	18,6	37,4	119,5	342,85
V4	2			10,9	24,9	78,4	124,15
V4	3		7,4	10,5	41,2	143,5	197,65
CG14	1		12,6	20,9	39,7	94,5	338,1
CG14	2						192,95
CG14	3		9	16,2	36,5	91	226,6
Hand weeded 0N							
Moro	1		5.1	5.1	12.5	49.1	236,57
Moro	2		10.5	16.1	40.8	93.3	352,1
Moro	3		5.5	11.4	26.2	83.5	254,57
V4	1		4.1	10.6	18.4	66.3	121,63
V4	2		5.9	11.6	24.1	70.9	228,35
V4	3		4.6	7.2	31.2	82.9	415,02
CG14	1		3.9	13.4	63.7	41	210,2
CG14	2		12.1	20.9	*	*	236,37
CG14	3		6.5	11.4	25.6	10.3	293,03

Data rice hydromorphic zone

grams/ 0.25m²

		Total DM harvest	Laef dry weight	Panicle dry weight	stem dry weight
Weed free + N					
	rep				
Moro	1				
Moro	2	351,9	62,2	144,3	145,4
Moro	3	266,4	40,5	118	107,9
V4	1	260,2	29,3	121,2	109,7
V4	2	189,7	26,2	76,3	87,2
V4	3	198,5	23,2	100	75,3
CG14	1	309,5	49,6	128,9	131
CG14	2	250,9	30,6	124,7	95,6
CG14	3	338,6	53,8	131,6	183,2
Weed free 0N					
	rep				
Moro	1	276,2	53,8	92,4	130
Moro	2	302,4	53,4	112,7	136,2
Moro	3	209,7	39,3	77,9	92,5
V4	1	125,8	16,5	58,2	51,1
V4	2	187,4	23,4	90,3	73,7
V4	3		20,8		71,6
CG14	1	148	18,5	76,1	53,4
CG14	2	256,4	31,5	121,8	103,1
CG14	3	244,4	32,5	111,9	100
Hand weeded +N					
	rep				
Moro	1				
Moro	2				
Moro	3				
V4	1				
V4	2				
V4	3				
CG14	1				
CG14	2				
CG14	3				
Hand weeded 0N					
	rep				
Moro	1	155	26.1	47.9	81
Moro	2	214.2	37.5	82.6	94.1
Moro	3	264.4	43.4	112.7	108.3
V4	1	88.3	12.2	33.1	43
V4	2	126.6	16.2	56	54.4
V4	3	181.2	17.7	76.3	87.2
CG14	1	105.4	15.3	33.8	56.3
CG14	2	228.9	27.3	114.8	86.8
CG14	3	142.7	19.4	55.6	67.7

Weed data upland

		grams/m² 28 DAS	grams/0,25m² 35 DAS	42 DAS	56 DAS	84 DAS	harvest
Hand weeded +N							
	rep						
Moro	1			1,5	4,2	20,1	38,5
Moro	2			0,5	1,7	6	26,8
Moro	3			1,5	3,3	17,9	47,2
V4	1			1,6	4	7,1	25,8
V4	2			0,7	4	15,7	24,6
V4	3			0,6	5,2	27,3	43,6
CG14	1			0,5	2,9	2,8	11,8
CG14	2			1,2	6	8,7	10,3
CG14	3			0	0,5	2,9	11,1
Hand weeded 0N							
	rep						
Moro	1		1	0,8			13,1
Moro	2	#72	0,3	0,6	#28,7	#81,2	21,4
Moro	3		1	0,5			48,1
V4	1		0,8	1			31,1
V4	2	#92	0,7	1,2	#23,3	#48,2	32,5
V4	3		0,4	0,4			62,6
CG14	1		0,4	0,9			9,1
CG14	2	#72	0,6	0,6	#17,6	#27,8	25,5
CG14	3		0,2	0,2			24,3

Weed data hydromorphic zone

Hand weeded +N							
	rep						
Moro	1			1,5	4,2	6,6	18,7
Moro	2			2,7	8,6	12,6	16,8
Moro	3						
V4	1			2,4	4,9	3	19,4
V4	2			1,6	4,8	19,3	27,9
V4	3			1,2	3,3	16,5	18,8
CG14	1			0,5	3,1	1,3	1
CG14	2						
CG14	3			1,3	4,3	7	12,6
Hand weeded 0N							
	rep						
Moro	1		2	2,5			
Moro	2	#40,8	2,5	1,9	#34,9	#64,8	
Moro	3						
V4	1		2	1,7			
V4	2	#18,4	1,1	1,5	#25,4	#60,5	
V4	3		3	1,5			
CG14	1		1,6	2			
CG14	2	#12,4			#19,1	#18,5	
CG14	3		1,9	1,8			

The measurements with # are grams/m² and average of the three replications