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1 **AGRO-ECONOMIC CHARACTERIZATION OF RICE PRODUCTION**
 2 **IN A TYPICAL IRRIGATION SCHEME IN BURKINA FASO**

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 4 Z. SEGDA^{1*}, S.M. HAEFELE², M.C.S. WOPEREIS³, M.P. SEDOGO¹ and S. GUINKO⁴

5
 6 ¹ Institut de l'Environnement et de Recherches Agricole (INERA), 04 BP 8645, Ouagadougou
 7 04, Burkina Faso.

8 ² West Africa Rice Development Association (WARDA), BP 96 St. Louis, Senegal

9 ³ An International Center for Soil Fertility and Agricultural Development (IFDC) - Africa
 10 Division, BP 4483, Lomé, Togo

11 ⁴ Université de Ouagadougou (UO), 03 BP 7021 Ouagadougou 03, Burkina Faso

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Received -----

26 * Corresponding author: Tel: + 226 77 01 87; Fax: + 226 77 02 37; E-mail:

27 zacharie.segda@messrs.gov.bf / zacharie.segda@coraf.org

28
 29
 30
 31
 32

Contact during review and production: Dr. S.M. Haefele; current address: International Rice
 Research Institute (IRRI), DAPO box 7777, Metro Manila, Philippines; E-mail:

s.haefele@cgiar.org

1 **AGRO-ECONOMIC CHARACTERIZATION OF RICE PRODUCTION** 2 **IN A TYPICAL IRRIGATION SCHEME IN BURKINA FASO**

3 4 **ABSTRACT**

5 Yield, yield gaps, input use, N-use efficiency, productivity and profitability of
6 irrigated rice in Burkina Faso were determined for a typical 1,000 ha irrigation scheme in the
7 dry season 1999 and the wet season 2001. Objectives were to analyse agro-economic
8 constraints and opportunities and determine ways to overcome such constraints.

9 The crop growth simulation model RIDEV was used to analyse farmers' crop
10 management practices, revealing considerable differences between actual and optimal
11 (according to RIDEV simulations) timing of crop management interventions. This diversity
12 of cropping practices caused considerable variation of internal efficiency of N (IEN), partial
13 factor productivity of nitrogen (PFPN), nitrogen recovery fraction (RFN), rice grain yields
14 and net benefits of N-use. Analyses of nitrogen uptake showed a clear relation between plant
15 N uptake and yield (mean IEN of 48 kg grain kg⁻¹ N uptake in farmers' fields), but the
16 relation between N applied and yield was scattered. PFPN varied from 16 to 52 kg grain kg⁻¹
17 N applied (mean of 35 kg grain kg⁻¹ N applied) due to a large range of fertilizer N recovery
18 rates (RFN = 7 to 77% of applied N; mean of 37%). Farmers' average yields were 4.9 t ha⁻¹
19 in the DS and 3.6 t ha⁻¹ in the WS, but yields were very variable and ranged from 0.9 to 7.9 t
20 ha⁻¹ in the DS and from 1.0 to 7.9 t ha⁻¹ in the WS. Yield gaps between average farmer's yield
21 and best farmer's yield were high (3.0 t ha⁻¹ in the DS and 4.3 t ha⁻¹ in the WS), indicating
22 considerable scope for yield increases in both seasons. Net benefits to irrigated rice cropping
23 were mostly positive (in average 418 US\$ ha⁻¹) in the dry season, but small (in average 108
24 US\$ ha⁻¹) in the wet season due to lower average yields and a lower paddy price. Partial
25 budget analysis of fertilizer use revealed considerably lower value/cost ratios of fertilizer use
26 in the wet season (mean V/C: 1.5) compared to the dry season (mean V/C: 2.9). Farmer's

1 knowledge of existing recommendations was imperfect, partly explaining the non-adoption of
2 these technologies. Other factors included problems with collective and individual planning
3 of the cropping calendar for two rice crops per year on the same field, and the need to also
4 attend to rainfed crops outside the scheme. It was concluded that improved crop management
5 practices are the key to reach higher yields and financial returns without additional
6 investments.

7 *Key Words:* Burkina Faso, Irrigated rice, *Oryza sativa* L., Nitrogen-use efficiency,
8 Profitability, crop simulation modeling, Yield gap.

9

10 **Abbreviations**

11 **CF**, cotton fertilizer i.e. mixed NPK fertilizers; **CL**, clay loam soil; **DAS**, day after sowing;
12 **DAT**, day after transplanting; **DS**, dry season; **FCFA**, Francs CFA; **IEN**, internal efficiency
13 of nitrogen; **PFPN**, partial factor productivity of nitrogen; **RFN**, nitrogen recovery fraction;
14 **SD**, standard deviation; **SL**, sandy loam soil; **T_F**, farmers' fertilizer practice; **T₀**, farmers'
15 fertilizer practice but without fertilizers; **WS**, wet season.

16

17 **INTRODUCTION**

18 Rice consumption in Burkina Faso is growing at 3% per year, especially due to
19 increased demand in urban centers (Randolph, 1997). Although the total surface area grown
20 to irrigate rice is relatively small (only 20% of total rice area), its contribution to marketed
21 national production is substantial (about 50%) and still growing (WARDA, 1996). Annual
22 paddy production during recent years (1996 to 2000) was about 100,000 t yr⁻¹, with imports
23 ranging from 105,000 to 240,000 t yr⁻¹ (FAO, 2002).

24 Although the potential of irrigated rice (*Oryza sativa* L.) in the Sahel is as high as 8 to
25 12 t ha⁻¹ (Dingkuhn and Sow, 1997) and best farmers regularly achieve paddy yields of 7 to 9

1 t ha⁻¹, various authors confirmed average yields of 3.0 to 5.5 t ha⁻¹ in Sahelian irrigated
2 systems (Miézan and Sié, 1997; Matlon et al., 1996; Wopereis et al., 1999, 2001; Haefele et
3 al., 2001, 2002). Average yields of irrigated rice in Burkina Faso were estimated at 4.0 to 4.5
4 t ha⁻¹ (Illy, 1997; Wopereis et al., 1999). These medium to low average yields are far below
5 the level anticipated by authorities and irrigation scheme planners, and threaten the economic
6 sustainability of irrigated rice in the region. Low yields combined with high input prices
7 cause low profit margins, which subsequently reduce savings for maintenance of
8 infrastructure and machines and the return of credit debts to the bank. Burkinabè rice
9 producers face competition from cheap Asian rice imports, and price increases on the local
10 markets cannot be expected in the near future. Therefore, the economic viability of the costly
11 irrigation schemes in the Sahel can be questioned (Bélières et al. 1997).

12 This background demonstrates the urgent need to improve productivity while
13 maintaining input costs at or close to the present level. Considerable increases of investments
14 in inputs are not likely due to the limited financial means of small-scale farmers. But crop
15 management adjusted to the local environment can contribute to improved productivity at
16 current input levels. Farmers growing irrigated rice in the Sahel have to cope with large
17 temperature fluctuations during the year. Low temperatures at panicle initiation during the
18 wet season and high temperatures around flowering during the dry season may cause spikelet
19 sterility and, therefore, substantial yield losses. Therefore, timing of sowing and the type of
20 cultivars to be used (short or medium duration) is critical, especially if two rice crops per year
21 are grown on the same field. Moreover, optimal timing of other crop management
22 interventions, such as weeding, fertilizer applications and harvesting depend on crop
23 development stages, which are also influenced by temperature. Sub-optimal fertility
24 management, late transplanting, sub-optimal weed management, spikelet sterility, and late
25 harvesting have been identified as wide spread agronomic constraints and have an important

1 impact on rice productivity, resource use efficiency and return to investments (e.g. Wopereis
2 et al., 1999; Haefele et al., 2000, 2001).

3 Evaluating improved soil fertility and weed management practices with farmers in
4 Mauritania and Senegal confirmed these findings. Improved fertilizer management increased
5 grain yield by 0.9 t ha⁻¹, while the recommended weed management resulted in a yield
6 increase of 1.0 t ha⁻¹. The effect of recommended management practices was additive and
7 gave a mean yield increase of 1.8 t ha⁻¹ compared to farmers' practices (Haefele et al., 2000).
8 In a similar but larger study, Kebbeh and Miézan (2003) could prove that considerable
9 productivity gains with lower production risk were possible without increasing costs, through
10 sequential adoption of integrated crop management options.

11 To improve the productivity of rice-based systems, agronomic and socio-economic
12 contributors to input-use efficiency and productivity need to be characterized. Field-level data
13 on cropping practices of Burkina Faso rice farmers are, however, rare. The objective of this
14 study was to identify constraints and opportunities for irrigated rice cropping in Bagré. The
15 irrigation scheme of Bagré in eastern central Burkina Faso is one of the many typically large
16 irrigation schemes that were installed to improve food security after the devastating droughts
17 in the 1970's and 1980's. Rice is the dominant crop in most of these irrigation schemes. The
18 study intended to analyse site-specific constraints and opportunities of irrigated rice
19 production in order to increase productivity and profitability. More specifically our aim was
20 to: (i) provide an overview of key crop and soil management practices, (ii) determine the
21 relative importance of crop management practices and soil quality parameters on rice
22 productivity, and (iii) characterize the economic performance of rice farming. The results can
23 then be used to propose alternative crop management practices that may increase input-use
24 efficiency and productivity.

1 MATERIAL AND METHODS

2 Site and cropping system

3 The Bagré irrigation scheme (11°30`N, 0°25`W) is located in the eastern part of
4 Burkina Faso, on the central plateau. The scheme is situated in the Boulgou province,
5 approximately 150 km Southeast of the capital Ouagadougou and about 50 km north of the
6 border to Togo. The African basement complex and Precambrian sediments determine the
7 geology of the region, but soils in the irrigation scheme are developed in alluvial sediments of
8 Quaternary age. Frequent primary minerals are biotite and amphibole, and dominating clay
9 minerals are montmorillonite and kaolinite (BUNASOLS, 1994). Soils of the irrigation
10 scheme (600 ha on the left bank of the Nakambe river) were classified according to the
11 French system as "sols bruns eutrophes tropicaux" and "sols ferrugineux tropicaux lessivés
12 hydromorphes" (BUNASOLS, 1994). Soil depth was on average between 0.4 to 1.2 m.

13 The climate is typical for the agro-ecological zone of the Sudan Savannah with
14 average rainfall of 900 mm yr⁻¹ in the wet season from July to October, followed by a cold
15 dry season in November to February and a hot dry season from March to June. Minimum air
16 temperatures below 15°C occur in the cold dry season and maximum air temperatures above
17 40°C occur in the hot dry season.

18 Irrigation water for the Bagré irrigation scheme is supplied by the Bagré dam, which
19 was built in 1994. The Bagré dam supplies water for gravimetric irrigation of arable land
20 downstream, both left and right of Nakambe River (formerly White Volta). Cultivation of the
21 first irrigation perimeter started in 1997, when the "Technical Mission of China" completed
22 irrigation and drainage infrastructure of 250 ha on the right riverbank. Another 750 ha were
23 completed in 2001 and construction is ongoing. The study presented was conducted in the
24 first completed irrigation scheme (Nimatoulaye perimeter or V1), which consists of 124
25 fields of a size between 0.6 and 1.0 ha (total area of 106 ha) and is cultivated by 124 farmers

1 organized in a farmer union (Giankouma). The union negotiates with the Bagré Dam
2 authority, purchases inputs and distributes them, organizes the irrigation, and decides on
3 credits. The union also recommends cultivars and arranges seed availability, but farmers are
4 free to choose among several cultivars available. Crop establishment method is chosen jointly
5 according to the needs of scheme management.

6 The main crop is irrigated rice, which is cultivated in the wet season (WS; sowing
7 from July to August) and the hot dry season (DS; sowing from January to February). Almost
8 100% of the irrigated area is cropped twice a year. Direct seeding and transplanting are both
9 practiced. Land is prepared using animal traction, and manual harvest and threshing is
10 dominating. Existing fertilizer recommendations are 300 kg ha⁻¹ "cotton fertilizer" (elemental
11 NPK 14:10:12) applied basal or shortly after transplanting and 100 kg ha⁻¹ urea (46:0:0) in
12 the WS or 150 kg ha⁻¹ urea in the DS. Recommended total NPK dose therefore is 88:30:35 kg
13 ha⁻¹ and 111:30:35 kg ha⁻¹ in the WS and DS respectively. Urea is recommended to be top-
14 dressed in two equal splits at early tillering and panicle initiation. Dominating cultivars are
15 FKR19 (TOX 728-1) and FKR14 (4418). Apart from irrigated rice, most farmers grow
16 rainfed maize, millet or sorghum in the surroundings of the scheme during the wet season and
17 some farmers grow vegetables during the dry season. In addition, most farmers also own
18 some cattle.

19

20 **Field Surveys**

21 Field and farmer surveys were conducted during the dry season (DS) 1999 and the wet
22 season (WS) 2000. Farmer participation was on a voluntary basis and not randomised.
23 Twenty farmers were selected before the start of both seasons, but the final sample was
24 smaller due to mismanagement of the experimental protocol by some farmers.

25 Agronomic practices were monitored with assistance of extension officers.

1 Participants were asked to establish a sub-plot of 10 m x 10 m in their field, separated from
2 the main field by bunds. Farmers were requested to manage their rice crop as usual, i.e. with
3 their own choice of fertilizer applications and their usual crop management practice (T_F). No
4 recommendations were given to farmers prior to the start of the surveys. The sub-plots were
5 managed using the same crop management practices as in T_F , but no fertilizer was applied
6 (T_0). All crop management practices were recorded through weekly interviews with farmers
7 during the growing season. Above ground rice-N-uptake in T_0 plots and comparison of N-
8 uptake in T_F and T_0 treatments was used to estimate indigenous soil N supply and the
9 recovery rate of applied nitrogen (Dobermann and White, 1999; Wopereis et al., 1999).

10 Paddy yields and grain moisture content were measured from a 6-m² area harvested in
11 each T_0 and T_F plot. Grain yields were corrected to 14% moisture content (or to 3% moisture
12 content for N uptake calculations). Harvest index was determined from oven-dry (70°C
13 resulting in 3% moisture content) straw and grain weight of a 12-hill sub-sample or a 0.5 m²
14 area in case of direct seeding. N concentrations in grain and straw samples were determined
15 using the standard Micro-Kjeldahl procedure (Bremner, 1996).

16

17 **Crop simulations**

18 The model RIDEV developed for Sahel and Sudan Savannah regions (Dingkuhn,
19 1997) was used to evaluate the timing of farmers' crop management practices. The model
20 estimates crop growth duration and spikelet sterility due to cold or heat stress. Inputs for the
21 model are daily minimum and maximum air temperature, photothermal constants of the
22 cultivar used, sowing date, and establishment method (transplanting or direct seedling).
23 Outputs are predictions of growth duration, spikelet sterility due to heat or cold stress, and
24 phenological stages of the rice crop, i.e. start of tillering, panicle initiation, heading,
25 flowering and maturity. This feature helps the user to determine optimal timing of N fertilizer

1 application (two splits coinciding with the start of tillering and panicle initiation, or three
 2 splits adding a third application at heading), timing of the last drainage before harvest (two
 3 weeks before maturity), and timing of harvest (at physiological maturity).

4 Because weather data from the survey site were not available, historical data from the
 5 weather station at Fada N’Gourma (12°05' N et 0°26' E) at 150 km from the Nimatoulaye
 6 irrigation scheme and from the years 1969 to 1979 were used for the simulations (Figure 1).
 7 Photothermal constants of the cultivar used by most farmers were not available in the RIDEV
 8 database. We selected cultivars similar to the ones used by the farmers in the RIDEV
 9 database (medium duration cultivar 4456 for farmers cultivar 4418 and short duration cultivar
 10 IR13240-108-2-2-3 for farmers cultivar TOX 728-1).

11

12 **Indicators of input use efficiency**

13 Soil N supply was estimated from plant N uptake in T_0 plots. Partial-factor
 14 productivity of applied N (PFPN) is the amount of grain produced per unit nitrogen applied
 15 and is calculated based on total grain yield at maturity in a treatment where N was applied
 16 (GY_{+N} in $kg\ ha^{-1}$) and the amount of fertilizer N applied (FN in $kg\ ha^{-1}$) according to $PFPN =$
 17 GY_{+N}/FN (Cassman et al., 1996). Recovery fraction of applied N (RFN) is calculated from
 18 total aboveground nitrogen uptake at physiological maturity in plots that received applied N
 19 (UN_{+N}) at the rate FN ($kg\ ha^{-1}$), and total aboveground N uptake in plots without N
 20 application (UN_{0N}) according to the equation: $RFN = (UN_{+N} - UN_{0N})/FN$. Internal efficiency
 21 of nitrogen (IEN) is defined as grain yield per kg nitrogen taken up and is calculated as $IEN =$
 22 GY/UN .

23

24 **Soil Analysis**

25 Five topsoil samples (0.0 to 0.2 m depth) were taken in each T_0 plot before the onset

1 of each growing season and composited. They were analysed for $\text{pH}_{\text{H}_2\text{O}}$ (1:2,5 extract),
2 electrical conductivity of the 1:5 soil-extract (EC), P-Bray1, and exchangeable bases
3 (extraction with ammonium chloride) using the methods described by van Reeuwijk (1992).
4 The Walkley-Black method (Nelson and Sommers, 1982) was used to determine total C, and
5 total N was determined according to Bremner (1996). Chemical analyses were conducted in
6 laboratories of the West African Rice Development Association in Senegal, the national
7 agricultural research institute "Institut de l'Environnement et de Recherches Agricoles"
8 (INERA) and the national soil survey agency "Bureau National des sols" (BUNASOLS) in
9 Burkina Faso.

10

11 **Economic Analysis**

12 The surveys determined actual farmers' practices and gathered information on
13 prices/costs of inputs, services and products, sufficient for economic analysis of crop
14 production. A key parameter in these calculations was the paddy price. Producers of Bagré
15 achieved an average paddy price of 105 FCFA kg^{-1} in the 1999 DS and 100 FCFA kg^{-1} in the
16 2000 WS. Over the period of the presented surveys, the average exchange rate of the West
17 African currency FCFA to the Dollar was US\$ 1.00 = 650 FCFA.

18 Fertilizer applications were evaluated for their returns and their costs on a per hectare
19 basis, using the T_0 and T_F plots. For the partial budget analysis of fertilizer use (CIMMYT,
20 1988; Crawford and Kamuanga, 1991), fertilizer-use related costs as well as harvest-related
21 in-kind costs sensitive to yield were needed. Harvest-related costs due to fertilizer application
22 were calculated by multiplying total harvest costs (including costs for harvesting, threshing,
23 bagging) of T_F with the relative importance of the yield increase due to fertilizer application
24 ($(\text{yield } T_F - \text{yield } T_0) / \text{yield } T_F$). Fertilizer costs included costs of all fertilizers and their
25 application. Total budget analysis included all production costs. Cumulative distribution

1 functions of returns were plotted to visualize farmers' economic performance (Hardaker et al.,
2 1997).

3

4 **Statistical Analysis**

5 Statistical analysis followed methods described by Gomez and Gomez (1983) using
6 STATISTICA software (StatSoft, inc.). Treatment means were compared with the Duncan
7 multiple range test. The P-level used for significance in the analysis of variance was always
8 0.05 and in the Duncan multiple range test alpha was set to 0.05.

9

10 **RESULTS**

11 **Soil analysis**

12 Most fields sampled had a slightly acidic pH and were within a favourable range for
13 rice growth (Table 1). Observed values of electrical conductivity (EC) were very low and
14 proved the absence of soil salinity. Both major texture groups of the scheme were
15 characterized by medium total soil organic carbon concentrations, but total soil N
16 concentrations were low and C/N ratios were above 20. Total cation exchange capacity was
17 medium for clay loam soils and low for sandy loam soils, and calcium and magnesium were
18 the dominating exchangeable cations. Soil test results showed that available K levels were
19 low and in the range of critical levels for K availability in rice soils (from 0.1 to 0.4 cmol kg⁻¹
20 according to Dobermann et al., 1995). Similarly, extractable Bray-1-P values were relatively
21 low with higher values in sandy loam soils, and the average values of both texture groups (4.9
22 and 6.2 mg P kg soil⁻¹) overlap with critical levels reported in the literature (Sanchez, 1976).
23 Observed values of soil parameters correspond well with observations of the national soil
24 survey agency "Bureau National des Sols" (BUNASOLS, 1994).

1 **Farmer's crop management**

2 Twenty farmers took part in the surveys each campaign, but 4 farmers in the 1999 dry
3 season and 8 in the 2000 wet season did not follow the experimental protocol and were
4 excluded from the analysis. Land preparation of all farmers consisted of animal driven
5 mechanical soil tillage, but only about 60% collaborating farmers owned a pair of cattle and a
6 plough. All farmers practiced pre-irrigation, ploughing and field leveling for land preparation.

7 The main cultivar used in both seasons was TOX 728-1 (100% in the 1999 DS and
8 90% in the 2000 WS), followed by the variety 4418. Farmers clearly had problems to follow
9 recommendations of critical sowing dates (before 25 July in the WS and 15 February in the
10 DS), to avoid yield losses due to spikelet sterility as a consequence of extreme temperatures.
11 Average sowing date in the wet season was 8 August and latest sowing date was 28 August.
12 Especially late sowing dates in the wet season increase the risk of spikelet sterility due to cold
13 stress in the reproductive phase, as was confirmed by RIDEV simulations (Fig. 2). According
14 to these simulations, substantial yield loss due to cold sterility can be expected for sowing
15 dates after mid of August. In farmers fields, direct seeding after the second half of August
16 resulted in lower average yields (2.7 t ha^{-1}) than earlier sowing dates (4.0 t ha^{-1}). The same
17 trend was observed for farmers practicing transplanting: average yields of 5.2 t ha^{-1} were
18 achieved by farmers transplanting between 16 and 20 August, transplanting later in August
19 resulted in average yields of 4.0 t ha^{-1} , and transplanting in September resulted in very low
20 yields (2 t ha^{-1}). Regardless of crop establishment method, best yields were achieved with
21 sowing dates not later than 18 August. Sowing dates in the dry season varied between 10
22 January and 10 February, but the RIDEV simulations do not indicate high sterility risks
23 depending on DS sowing date. Nevertheless, late DS sowing dates will shorten the time
24 between the DS and the WS crop and might thereby cause delays of the onset of the WS.

25 Most farmers used direct seeding in the dry season (82%) and transplanting in the wet

1 season (67%), in agreement with existing recommendations. All farmers used about 40 kg
2 ha^{-1} seed when transplanting, and about 45 - 60 kg ha^{-1} for direct seeding in rows.
3 Considerable differences between farmers were observed regarding the age of seedlings at
4 transplanting (18 – 26 DAS in the wet season and 28 – 39 DAS in the dry season), and the
5 transplanting density (0.20 x 0.20 m to 0.25 x 0.25 m). Research recommended seedling age
6 at transplanting is 20 days in the WS and 30 days in the DS due to delayed plant development
7 caused by low temperatures in December and January.

8 Fertilizers used by farmers were urea (46% N) combined with two different mixtures
9 of "Cotton Fertilizer (CF)" i.e. elemental NPK mixtures of 12:11:10% or 14:10:14%. Organic
10 fertilizer (animal manure mixed with rice straw) was only used by four farmers in the 2000
11 WS. Average quantity of CF applied was 213 kg ha^{-1} in the WS and 197 kg ha^{-1} in the DS.
12 Thereby, farmers applied in average 22 kg P ha^{-1} and 21 kg K ha^{-1} in the WS and 21 kg P ha^{-1}
13 and 20 kg K ha^{-1} in the DS. Average quantities of N applied were 99 kg N ha^{-1} (between 81
14 and 122 kg N ha^{-1}) in the 1999 dry season, and 100 kg N ha^{-1} (between 64 and 145 kg N ha^{-1})
15 in the 2000 wet season. Thus, average N doses were close to recommended doses but were
16 highly variable between farmers. Urea was applied top-dressed and almost all farmers applied
17 urea in two splits. In the WS 2000 almost all farmers applied the first urea split together with
18 CF around early tillering, and the second split was applied around panicle initiation (8
19 farmers) or closer to booting (4 farmers). In the DS 1999 urea was rarely applied together
20 with CF and most farmers applied urea at panicle initiation and booting. The considerable
21 variability in application timing of farmers practice compared to optimal timing as simulated
22 with RIDEV is shown in Figure 3.

23 Most farmers conducted two weedings each season. Preferred weed control method
24 was manual weeding and only in the wet season 5 out of 12 farmers used herbicides (Ronstar,
25 120 g ai l^{-1}). Quantities applied (1 l ha^{-1}) were far below the recommended dose of 4 l ha^{-1} .

1 The first manual weeding was done between 13 - 67 DAS in the WS and between 15-40 DAS
2 in the DS (in average 26 days after transplanting or direct-sowing). The second manual
3 weeding was practiced on average 61 days after transplanting in the wet season and 57 days
4 after direct sowing in the dry season. Two farmers in the wet season practiced manual
5 weeding before transplanting. Farmer's weed management practice compared to optimal
6 timing as simulated with RIDEV is shown in Figure 3. Four farmers used insecticides
7 (cypermethrine) in the wet season.

8 Farmers harvested manually, on average 128 DAS in the wet season (between 110 and
9 145 DAS), and 117 DAS in the dry season (between 103 and 132 DAS) (Fig. 3). RIDEV
10 simulations for TOX 728-1 recommend harvest at about 124 DAS (133 DAT) and 109 DAS
11 (118 DAT) for sowing dates in July and February respectively.

12

13 **Yields and yield gap estimation**

14 Average T_0 and T_F yields separated for the two texture groups and both seasons are
15 presented in Table 2. The influence of soil texture on grain yield of fertilized and non-
16 fertilized soils is similar in both seasons. Paddy yields on clay loam soils were always higher
17 than on sandy loam soils, and the difference increased with fertilization. The difference was
18 significant only for fertilized plots in the 1999 DS and for unfertilized plots in the 2000 WS.

19 Average yield gaps between best farmer's yield, average farmer's yield and T_0 yields
20 for the 1999 DS and the 2000 WS are shown in Figure 4. In both seasons, best farmers
21 achieved yields of almost 8.0 t ha^{-1} . The yield gap between best and average farmers yield
22 was 3.0 t ha^{-1} in the DS and 4.3 t ha^{-1} in the WS. Average yields with fertilization (T_F) were
23 4.9 t ha^{-1} in the DS and 3.6 t ha^{-1} in the WS, but yields were very variable and ranged
24 between 0.9 and 7.9 t ha^{-1} in the DS and between 1.0 and 7.9 t ha^{-1} in the WS. Without
25 fertilization (T_0), grain yields of 1.7 t ha^{-1} in the DS and 1.9 t ha^{-1} in the WS were achieved.

1 **Indigenous soil nitrogen supply and N-use efficiency**

2 Aboveground plant N uptake in T_0 plots was used to estimate indigenous soil N
3 supply (INS), assuming that in most unfertilised soils N will be the most limiting element for
4 crop growth. Nitrogen uptake of the crop without fertilizer application revealed large
5 differences in INS, ranging from 9 to 102 kg N ha⁻¹ in the 2000 WS with an average of 37 kg
6 N ha⁻¹. The relation between grain yield and total aboveground N uptake at maturity (internal
7 N use efficiency; IEN) for the 2000 wet season is presented in Figure 5a, showing a linear
8 relation between both parameters. Envelope lines of maximum dilution and accumulation of
9 N in modern rice cultivars according to Witt et al. (1999) were added and reveal N
10 accumulation for T_F plots (IEN: 48 kg grain per kg N taken up). Average IEN for T_0 plots
11 was 51 kg grain per kg N taken up, which is close to values reported by Cassman et al. (1997)
12 in Asian irrigated rice systems.

13 Although the relation between N uptake and yield was strong, no relation was found
14 between the quantity of N applied and observed grain yield (Figure 5b), neither for clay loam
15 nor for sandy loam soils. Partial factor productivity of N varied from 16 to 52 kg grain per
16 kg⁻¹ N applied with an average of 35 kg grain kg⁻¹ N applied. Very low observed PFPN
17 values showed the variability of efficiency, e.g. one farmer achieved a yield of 3.2 t ha⁻¹ by
18 applying 70 kg N ha⁻¹ whereas an other farmer applied 122 kg N ha⁻¹ to yield only 2.7 t ha⁻¹.
19 These differences can largely be explained by highly variable fertilizer N recovery rates.
20 Fertilizer N recovery was on average 37%, ranging from 13% to a maximum of 77% (Fig.
21 5c). Only three farmers achieved more than 50% recovery of applied N, whereas all other
22 farmers had recovery rates between 10 and 50%. No influence of soil texture type on N
23 recovery was detectable. The here observed average recovery rate is at the lower end of the
24 range reported for other Sahelian rice growing environments by Wopereis et al. (1999) and
25 Haefele et al. (2000, 2001, 2002). Nitrogen absorbed in T_0 plots was on average 37 kg N ha⁻¹,

1 ranging from 9 to a maximum of 102 kg N ha⁻¹ (Fig. 5d) versus an average of 74 kg N ha⁻¹
2 (17 to 156 kg N ha⁻¹) for fertilized plots. Natural soil fertility has a strong influence on the
3 nutrient uptake from added fertilizer, which can be seen from the relation between N uptake
4 in T₀ and T_F plots (Figure 5d) or from grain yields in T₀ and T_F plots in both seasons analysed
5 (grain yield T_F = 2.2 * grain yield T₀, r² = 0.44; data not shown). Grain yields and nitrogen
6 uptake showed no significant relation to the soil parameters presented in Table 1.

7

8 **Productions costs and farmer's economic performance**

9 Table 3 shows average total productions costs covering all costs for services, inputs
10 and labor in both seasons. Costs for maintenance were not included. Average total production
11 costs per hectare were between 261 561 and 285 352 FCFA (equivalent to 402 and 439 US\$)
12 and slightly higher in the 2000 WS. Fertilizers and irrigation were the most important cost
13 items in both seasons and covered together about 50% of total costs. Fertilizers were the most
14 important single cost item and represented about one third of total costs. Higher evapo-
15 transpiration and the absence of rains cause considerably higher irrigation costs in the dry
16 season.

17 The majority of farmers had positive net returns, and average total budget value/cost
18 ratios were 1.2 in the WS and 2.1 in the DS (Table 3). Negative net returns occurred more
19 frequently in the WS (4 out of 12 farmers), but concerned also 3 out of 16 farmers in the DS.
20 About two thirds of farmers in the wet season had low or even negative net benefits (Figure
21 6). Rice cropping was more beneficial in the DS, were about 80% of the farmers had medium
22 to high net benefits. Since average T₀ yields were almost identical in both seasons (Table 2),
23 low net benefits in the WS were mainly due to low returns to fertilizer use (see partial budget
24 for fertilizer use in Table 3) as indicated by the low value / cost ratio (1.5 in the WS 2000).

1 **DISCUSSION**

2 Chemical characterization of topsoil parameters served to determine some
3 characteristics influencing soil fertility in irrigated rice-based systems. General soil properties
4 like soil reaction (pH) and soil salinity (EC) were within favourable ranges for rice growth,
5 and high Ca and Mg saturation of the exchange complex as well as low Na saturation
6 indicated considerable buffer capacities with regards to both parameters. Most fields sampled
7 showed low values of total soil N, exchangeable K and extractable soil-P (Bray1 test). That
8 nitrogen and phosphorus are the main yield limiting elements in rice cropping was proven by
9 numerous fertilizer experiments in the region. Haefele et al. (2001) indicated that in the
10 Senegal River valley P availability became a limiting factor for rice crops at P-Bray1 values
11 below 4 mg kg⁻¹. In contrast, rice yield increases due to K application in fertilizer
12 experiments in the region were often small and rarely significant. A possible explanation is
13 that exchangeable K represents only a small part of the total soil K pool and that rice roots
14 can access soil K from other pools (Haefele et al., 2003b). Topsoils in the scheme were
15 characterized by medium to low soil organic matter content and total cations exchange
16 capacity according to the classification of BUNASOLS (1990). Increased use of organic
17 materials should be encouraged to maintain soil fertility and to supplement mineral fertilizers.
18 Segda et al. (2001) showed in the Kou Valley (Burkina Faso) that continuous use of organic
19 amendments (farmyard manure, compost, rice straw) improved rice production and the
20 efficiency of mineral fertilizers. Farmer's practice to remove most rice straw from the fields
21 might contribute to a reduction of indigenous soil fertility.

22 No relation could be detected between topsoil parameters measured and T0 yield or
23 plant N uptake, confirming reports by Dobermann et al. (2003) and Haefele (2001). In
24 irrigated rice, the cumulative effect of management depending factors like e.g. number of
25 seasons per year, duration of irrigation, organic residue management, soil aeration etc. seems

1 to affect indigenous soil fertility stronger than easily measurable chemical or physical soil
2 parameters (see Dobermann et al., 2003).

3 RIDEV simulations showed that especially wet season yields can be strongly
4 influenced by temperature induced yield losses depending on the sowing date (Figure 2).
5 Sowing after 15 August increased the risk of cold sterility due to low daily minimum
6 temperatures in November, i.e. during the reproductive growth stages. When transplanting,
7 critical sowing dates are about 10 days earlier due to the delay caused by the transplanting
8 shock. The simulation results were confirmed by the low yields of farmers with late sowing
9 date in the WS, and cold sterility due to late sowing date might be the single most important
10 reason for the low economic return of many farmers in the WS. In agreement with this
11 finding is the advice of Nebié (1995), who recommended transplanting not later than 15
12 August. Spikelet sterility due to high daily maximum temperatures in the DS as reported from
13 irrigated schemes further north (e.g. the Office du Niger in Mali; Dingkuhn 1997) does not
14 seem to be an important problem in the region. Nevertheless, farmers should establish the DS
15 crop in January or until mid February latest since delayed start of the WS is in most cases
16 directly related to a late start of the DS. To improve farmers respect of the cropping calendar,
17 they must be shown the consequences of delayed crop establishment in the WS in order to
18 improve their collective and individual crop management planning.

19 During a meeting with farmers after the WS, another reason for delayed establishment
20 of the WS rice crop was brought up. Several farmers mentioned that in the WS they gave
21 priority to (traditional) rainfed crops outside the scheme. Rainfed crops (sorghum, millet)
22 were conceived as to provide food security whereas the irrigated rice was regarded as cash
23 crop (see also Sory, 1996; Ouattara et al., 1996). Although this diversification of activities is
24 an important method of risk management, farmers must be made aware of the consequences
25 in order not to loose money and to maintain the economic sustainability of the irrigated crop.

1 Best farmers' yields were high above farmers' average yields in both seasons,
2 indicating a considerable yield gap. These yield gaps as well as the regular occurrence of
3 almost complete crop failure confirmed reports by Wopereis et al. (1999) and Haefele et al.
4 (2001, 2002) for other irrigated rice growing systems in the West African Sahel. The
5 contribution of late sowing in the WS to the yield gap was discussed above. In addition, sub
6 optimal crop management contributed to the yield gap in both seasons. The analysis of
7 farmer's crop management revealed considerable differences between actual and optimal
8 (according to RIDEV simulations) timing of crop management interventions (e.g.
9 transplanting, fertilizer application, weeding and harvest) (Fig. 3). But it should not be
10 overseen that apart from timing, the quality of individual management practices is equally
11 important. For example, even if farmers applied herbicides in time, they often used doses far
12 too low to avoid yield losses due to weeds.

13 In general, average fertilizer doses observed here are similar to farmers' practice in
14 Asia (e.g. Dobermann et al., 2002). For irrigated systems in Burkina Faso, comparable
15 fertilizer doses were reported by Nebié (1995) in Kou Valley and by Wopereis et al. (1999).
16 It remains questionable if the high doses of cotton fertilizer with fixed NPK ratios are good
17 practice, since their NPK ratio was developed for non-rice crops. Wopereis et al. (1999)
18 proposed a relative increase of the N dose and results of Haefele et al. (2003b) questioned the
19 need of K application for irrigated rice in the Sahel and Sudan Savannah at current cropping
20 intensities. Partial-factor productivity of applied N was similar to values reported by Cassman
21 et al. (1996) for Asia and by Wopereis et al. (1999) for West Africa. Analyses of nitrogen
22 uptake showed a clear relation between plant N uptake and yield, but the relation between N
23 applied and yield was scattered due to a large range of fertilizer N recovery rates. Identical
24 observations were made by several authors (e.g. Adhikari et al., 1999; Wopereis et al., 1999;
25 Haefele et al., 2000, 2001). Low internal efficiency of nitrogen in the WS according to

1 maximum N accumulation border lines as defined by Witt et al. (1999) and Haefele et al.
2 (2003a) indicate that either nutrients other than N were limiting yield (e.g. P or K) or that
3 yield was reduced by other factors (spikelet sterility, weed competition, pest and diseases).
4 Since considerable P and K doses were applied, the latter explanation seems more likely.

5 Remarkable is the clear relation between T_0 yields and T_F yields, which is found back
6 in the relation between plant N uptake in T_0 and T_F plots (only analysed for the WS). It could
7 be concluded, that the yield gain due to fertilizer application is similar in all fields, only
8 modulated by fertilizer recovery rates, which are dependent of the crop management quality.
9 This would make indigenous soil fertility the decisive factor for yield given a range of crop
10 management practices. It would also explain the absence of a relation between fertilizer (N)
11 applied and yield. But the presented database is too small to analyse these questions in more
12 detail.

13 Fertilizer and irrigation costs represented about 50% of total production costs, and are
14 a major investment for the surveyed small-scale farmers. Due to high production costs and
15 low yields, several farmers had low or negative returns to rice cropping. Dry season net
16 returns from investment were considerably higher than in the wet season. Wet season returns
17 were negative due to low average yields and a lower paddy price. As noted by Wopereis et al.
18 (1999), the DS in Burkina has a higher agronomic potential due to higher solar radiation and
19 the presented survey showed a high risk of spikelet sterility in the WS. Since most of the
20 production cost items in the WS cannot be reduced substantially and considerable paddy
21 price increases cannot be expected, higher input use efficiency must be achieved to make the
22 WS rice crop economically sustainable. The most promising ways to achieve this efficiency
23 increase is (i) to avoid seeding after 15 August, (ii) to improve timing and quality of crop
24 management practices, and (iii) to improve existing fertilizer recommendations. Especially
25 continuous high doses of P and K fertilizer do not seem to be necessary at the current wet

1 season yield level. Validation of the simulation model RIDEV for site-specific cultivars could
2 contribute to improved crop management planning in the region.

3

4 **CONCLUSIONS**

5 The results reported here illustrate the multitude of factors influencing the
6 performance of irrigated rice systems in the Bagré plain. Agronomic constraints were similar
7 as found for other schemes analysed in the region. Spikelet sterility due to extreme
8 temperatures was a major constraint in the wet season. Timing of crop management practices
9 was variable and often did not coincide with critical growth stages of the rice plant. Net
10 benefits to irrigated rice cropping were mostly positive in the DS but often low or even
11 negative in the WS. Yield gaps between average farmer's yield and best farmers' yield were
12 high and indicated considerable scope for yield and profit increases in both seasons. Farmer's
13 knowledge of existing recommendations was imperfect, partly explaining the non-adoption.
14 Other factors included problems with collective and individual planning of the cropping
15 calendar for double cropping of rice (two rice crops on the same field per year), and the need
16 to also attend to rainfed crops outside the scheme. To reach higher yields and financial
17 returns without additional investments, input use efficiency must be improved. Information
18 transfer, training of farmers and extension officers, and improved collective decision-making
19 is urgently necessary to improve productivity and profitability of irrigated rice cropping in
20 Bagre's plain.

21

1 **REFERENCES**

- 2 Adhikari, C., Bronson, K.F., Panuallah, G.M., Regmi, A.P., Saha, P.K., Dobermann, A., Olk,
3 D.C., Hobbs, P.R and E. Pasuquin. 1999. On-farm soil N supply and N nutrition in the
4 rice-wheat system of Nepal and Bangladesh. *Field Crops Res.* 64 (3): 273-286.
- 5 Belières, J.F., Camara, S. and E.H.A. Touré. 1997. Development in the economic and
6 technical performance of irrigated rice production in the Senegal river delta. p. 99-129. In:
7 Miézan, K. M., Wopereis, M.C.S., Dingkuhn, M., Deckers, J. and Randolph, T.F. (Eds.).
8 *Irrigated Rice in the Sahel: Prospects for sustainable Development* (In French, with
9 English abstract). West Africa Rice Development (WARDA), 27-30 march 1995, Bouaké,
10 Ivory Coast.
- 11 Bremner, J.M. 1996. Nitrogen-total. p. 1085-1121. *In*: D.L. Sparks et al., (ed.). *Methods of*
12 *Soil Analysis. Part 3. Chemical Methods*, Soil Science Study of America Book Series no 5.
13 Soil Sciences Society of America & American Society of Agronomy, Madison, WI, USA,
- 14 BUNASOLS 1990. Lands evaluation manual. Technical document No 6 (In French),
15 Ouagadougou, Burkina Faso.
- 16 BUNASOLS 1994. Pedological study of Bagré irrigated perimeter (Bagré aval, bief A and B,
17 first party), scale 1/10 000 è. Vol. 1: Main report, Technical report 95, (In French)
18 BUNASOLS, Ouagadougou, Burkina Faso.
- 19 Cassman, K.G., Gines, G.C., Dizon, M.A., Samson, M.I and J.M. Alcantara. 1996. Nitrogen-
20 use efficiency in tropical lowland rice systems: contributions from indigenous and applied
21 nitrogen. *Field Crops Res.* 47 (1), 1-12.
- 22 Cassman, K.G., Peng, S, and A. Dobermann. 1997. Nutritional physiology of the rice plant
23 and productivity decline of irrigated lowland rice systems in the tropics. *Soil Science and*
24 *Plant Nutrition* 43: 1111-1116.
- 25 CIMMYT. 1988. From agronomic data to farmer recommendations: an economics training
26 manual. International Maize and Wheat improvement center (CIMMYT), Mexico.
- 27 Crawford, E. and M. Kamuanga. 1991. Economic analysis of agronomic trials for the
28 formulation of farmer recommendations. Michigan State University (MSU) International
29 Development Papers Reprint No. 6F, 1987, MSU, East Lansing, Michigan, USA.
- 30 Dingkuhn, M. 1997. Characterizing irrigated rice environments with the rice phenology
31 model RIDEV. p. 343-360. *In*: Miézan, K. M., Wopereis, M.C.S., Dingkuhn, M., Deckers,
32 J. and Randolph, T.F. (eds.). *Irrigated Rice in the Sahel: Prospects for sustainable*
33 *Development*. West Africa Rice Development (WARDA), 27-30 march 1995, Bouaké,
34 Ivory Coast.

- 1 Dingkuhn, M. and A. Sow. 1997. Potential yields of irrigated rice in the Sahel. p. 361-379.
2 *In: Miézan, K. M., Wopereis, M.C.S., Dingkuhn, M., Deckers, J. and Randolph, T.F.*
3 *(eds.). Irrigated Rice in the Sahel: Prospects for sustainable Development. West Africa*
4 *Rice Development (WARDA), 27-30 march 1995, Bouaké, Ivory Coast.*
- 5 Dobermann, A., Cassman, K.G., Sta. Cruz, P.C., Neue, H.U., Skogley, E.O., Pampolino,
6 M.F., and M.A.A. Adviento. 1995. Dynamic soil tests for rice. p. 343-365. *In: Fragile*
7 *lives in Fragile Ecosystems. Proceedings of the International Rice Research Conference,*
8 *13-17 February 1995. International Rice Research Institute, Manila, Philippines.*
- 9 Dobermann, A., Witt, C., Dawe, D., Gines, H.C., Nagarajan, R., Satawathanant, S., Son,
10 T.T., Tan, P.S., Wang, G.H., Chien, N.V., Thoa, V.T.K., Phung, C.V., Stalin, P.,
11 Muthukrishnan, P., Ravi, V., Babu, M., Chatuporn, S., Kongchum, M., Sun, Q., Fu, R.,
12 Simbahan, G.C. and M.A.A. Adviento. 2002. Site-specific nutrient management for
13 intensive rice cropping systems in Asia. *Field Crops Res.* 74:37-66.
- 14 Dobermann, A., and P.F. White. 1999. Strategies for nutrient management in irrigated and
15 rainfed lowland rice systems. *Nutr. Cycl. Agroecosyst.* 53: 1-18.
- 16 Dobermann, A., Witt, C., Abdulrachman, S., Gines, H.C., Nagarajan, R., Son, T.T., Tan, P.S.,
17 Wang, G.H., Chien, N.V., Thoa, V.T.K., Phung, C.V., Stalin, P., Muthukrishnan, P., Ravi,
18 V., Babu, M., Simbahan, G.C., Adviento, M.A.A. and V. Bartolome. 2003. Estimating
19 indigenous nutrient supplies for site-specific nutrient management in irrigated rice. *Agron.*
20 *J.* (in press).
- 21 FAO, 2002. Commodity balances database. <http://apps.fao.org>
- 22 Gomez, K A. and A.A. Gomez. 1983. Statistical procedures for agricultural research. 2nd ed.
23 (IRRI), Los Baños, Philippines.
- 24 Haefele, S.M., 2001. Improved and sustainable nutrient management for irrigated rice-based
25 cropping systems in West Africa. Ph.D. diss, Hamburger Bodenkundliche Arbeiten.
- 26 Haefele, S.M., Johnson, D.E., Diallo, S., Wopereis, M.C.S. and I. Janin. 2000. Improved soil
27 fertility and weed management is profitable for irrigated rice farmers in Sahelian West
28 Africa. *Field Crops Res.* 66 (2): 101-113.
- 29 Haefele, S.M., Wopereis M.C.S., Donovan C. and J. Maubuisson. 2001. Improving the
30 productivity and profitability of irrigated rice production in Mauritania. *European Journal*
31 *of Agronomy* 14 (3): 181-196.
- 32 Haefele, S.M., Wopereis, M.C.S. and C. Donovan. 2002. Farmers' perceptions, practices and
33 performance in a Sahelian irrigated rice scheme. *Expl. Agric.* 38: 197-210.
- 34 Haefele, S.M., Wopereis, M.C.S., Ndiaye, M.K., Barro, S.E. and M. Ould Isselmou. 2003a.

- 1 Internal nutrient efficiencies, fertilizer recovery rates and indigenous nutrient supply of
2 irrigated lowland rice in Sahelian West Africa. *Field Crops Res.* 80 (1): 19-32.
- 3 Haefele, S.M., Wopereis, M.C.S., Schloeböhm, A. and H. Wiechmann. 2003b. Long-Term
4 Fertility Experiments for Irrigated Rice in the West African Sahel: Effect on soil
5 characteristics. *Field Crops Res.*, (in press).
- 6 Hardaker, J.B., Huirne, R.B. and J.R. Anderson. 1997. *Coping with risk in Agriculture*, New
7 York: CAB International.
- 8 Illy, L. 1997. The place of irrigated rice cropping in agricultural production systems in
9 Burkina Faso. p. 131-135. *In: Miézan, K. M., Wopereis, M.C.S., Dingkuhn, M., Deckers,*
10 *J. and Randolph, T.F. (Eds.). Irrigated Rice in the Sahel: Prospects for sustainable*
11 *Development (In French, with English abstract). West Africa Rice Development*
12 *(WARDA), 27-30 march 1995, Bouaké, Ivory Coast.*
- 13 Kebbeh, M. and K.M. Miézan. 2003. Ex-ante evaluation of integrated crop management
14 options for irrigated rice production in the Senegal River Valley. *Field Crops Res.* 81 (2-3):
15 87-94.
- 16 Matlon, P., Randolph, T.F. and R. Guei. 1996. Impact of rice research in West Africa.
17 International Conference on the impact of rice research, Bangkok, Thailand, 3-5 June
18 1996, WARDA, Bouaké, Ivory Coast.
- 19 Miézan, K.M. and M. Sié. 1997. Varietal improvement for irrigated rice in the Sahel. p. 443-
20 455. *In: Miézan, K. M., Wopereis, M.C.S., Dingkuhn, M., Deckers, J. and Randolph, T.F.*
21 *(Eds.). Irrigated Rice in the Sahel: Prospects for sustainable Development. West Africa*
22 *Rice Development (WARDA), Bouaké, 27-30 march 1995.*
- 23 Nebié, B. 1995. Study of agronomic and pedologic constraints that determine irrigated rice
24 production in Kou Valley in Burkina Faso (In French). Ph.D. diss. Sciences and Technique
25 Faculty, Nat. Univ. of Ivory Coast.
- 26 Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p.
27 539-579. *In: A.L. Page (ed.) Methods of Soil Analysis. 2nd Ed. ASA Monogr. 9 (2), Amer.*
28 *Soc. Agron. Madison, WI.*
- 29 Ouattara, S., Dembélé, Y. et Z. Zida. 1996. Cultural practices in small irrigated perimeters. p.
30 171-195 *In: Improving irrigated perimeter performances. Proceedings of irrigation project*
31 *regional seminar (In French). International Irrigation Management Institute (IIMI), 24-26*
32 *juillet 1996, Ouagadougou, Burkina Faso.*
- 33 Randolph, T.F. 1997. Rice demand in the Sahel. p. 71-88 *In: Miézan, K. M., Wopereis,*
34 *M.C.S., Dingkuhn, M., Deckers, J. and Randolph, T.F. (Eds.). Irrigated Rice in the Sahel:*

- 1 Prospects for sustainable Development. West Africa Rice Development (WARDA), 27-30
2 march 1995, Bouaké, Ivory Coast.
- 3 Sanchez, P.A. 1976. Properties and management of soils in the tropics. New York, USA.
- 4 Segda, Z., Lompo, F., Wopereis, M.C.S. and P.M. Sedogo. 2001. Use of compost in irrigated
5 rice system to improve soil fertility in the Kou Valley, Burkina Faso (In French, with
6 English abstract) *Agronomie Africaine* 13 (2): 45-58.
- 7 Sory, L. 1996. Impact of cropping system (irrigated and upland) on the irrigated rice
8 perimeter of Gorgo and Itenga (Province of Kouritenga – Burkina Faso). p. 27-30. *In: Bull.*
9 *of West African irrigation network (BRIAO), International Water Management Institute*
10 *(IWMI), N° 006, mai 1996 (In French), Special Burkina Faso, Irrigation: techniques and*
11 *management. Ouagadougou, Burkina Faso.*
- 12 Van Reeuwijk, L.P. 1992. Procedures for soil analysis, 3rd ed. ISRIC, Wageningen.
- 13 WARDA. 1993. Rice trends in sub-Saharan Africa. A synthesis of statistics on rice
14 production, trade and consumption. West Africa Rice Development Association
15 (WARDA), Bouaké, Ivory Coast.
- 16 Witt, C., Dobermann, A., Abdurachman, S., Gines, H.C., Wang Guanghuo, Nagarajan, R.,
17 Satawatananont, S., Tran Thuc Son., Pham Sy Tan., Le Van Tiem., Simbahan, G.C and
18 D.C. Olk. 1999. Internal nutrient efficiencies of irrigated lowland rice in tropical and
19 subtropical Asia. *Field Crops Res.* 63 (2): 113-138.
- 20 Wopereis, M.C.S., Donovan, C., Nebié, B., Guindo, D. and M.K. Ndiaye. 1999. Soil fertility
21 management in irrigated rice systems in the Sahel and Savanna regions of West Africa.
22 Part I. Agronomic analysis. *Field Crops Res.* 61 (2): 125-145.
- 23 Wopereis, M.C.S., Haefele, S.M., Kebbeh, M., Miezán, K M. and B.S. Diack. 2001.
24 Improving the productivity and profitability of irrigated rice production in Sahelian West
25 Africa. p. 117-142. *In: Yield gap and productivity decline. Proceedings of the expert*
26 *consultation held in Rome, 5-7 September 2000, FAO.*

1 **Table 1.** Average topsoil (0 – 0.2m) characteristics in fields of participating farmers in the dry
 2 season 1999 at Nimatoulaye, Burkina Faso.

3

Soil characteristics	11 observations Clay loam		9 observations Sandy loam	
	Mean	SD	Mean	SD
pH _{H2O} (1:2.5 soil extract)	6.6	0.7	6.6	0.2
EC (1:5 soil extract) (mS cm ⁻¹)	0.06	0.03	0.03	0.01
N total (%)	0.04	0.01	0.05	0.01
Total organic C (%)	1.6	1.0	1.2	0.3
Ca exchangeable (cmol _c kg ⁻¹)	4.8	2.6	3.1	0.8
Mg exchangeable (cmol _c kg ⁻¹)	2.1	1.4	1.4	0.7
Na exchangeable (cmol _c kg ⁻¹)	0.3	0.25	0.1	0.03
K exchangeable (cmol _c kg ⁻¹)	0.2	0.13	0.2	0.03
Total exchangeable bases (cmol _c kg ⁻¹)	7.5	4.3	4.7	1.4
P-Bray1 (mg kg ⁻¹ soil)	4.9	2.5	6.2	3.3

4

5

1 **Table 2.** Average grain yields in farmer's fields (T_F) and in unfertilised sub-plots (T_0) in
 2 Nimatoulaye (Burkina Faso) during the 1999 dry season and 2000 wet season. Results were
 3 analysed separately for the two dominating soil texture groups.

4

	Grain yield T_0		Grain yield T_F	
	Average	SD	Average	SD
1999 dry season				
Sandy loam soil (SL)	1.34 ns	0.79	3.98 b	2.01
Clay loam soil (CL)	2.07 ns	0.87	6.02 a	1.56
2000 wet season				
Sandy loam soil (SL)	1.25 b	0.42	2.84 ns	1.42
Clay loam soil (CL)	2.02 a	0.52	4.27 ns	0.65

5

6 Seasonal results in a column with the same letter are not significantly different according to
 7 the Newman Keuls test with $\alpha < 0.05$; ns means not significantly different; SD means
 8 standard deviation.

1 **Table 3.** Average production costs and some elements of total and partial budget analysis for
 2 farmers participating in the surveys during the 1999 dry season and the 2000 wet season in
 3 the Bagré irrigation scheme (Nimatoulaye, Burkina Faso).

4

	1999 dry season		2000 wet season	
	FCFA ha ⁻¹	%	FCFA ha ⁻¹	%
Average production costs				
Fertilizers	90 308	34.4	88 876	31.0
Water	52 800	20.2	31 948	11.2
Credit reimbursement	17 742	6.8	28 229	9.9
Crop establishment	17 754	6.8	24 585	8.6
Soil preparation	13 377	5.1	21 264	7.5
Threshing	21 592	8.3	19 586	6.9
Harvesting	12 230	4.7	20 979	7.4
Weeding	9173	3.5	20 958	7.3
Harvest bags	13 495	5.2	12 456	4.4
Seeds	10 797	4.1	9082	3.2
Fertilizer application	2293	0.9	1698	0.6
Chemicals	-	-	4 783	1.7
Chemical application	-	-	908	0.3
Total budget analysis				
Total cost	261 561		285 352	
Total revenue	533 223		355 825	
Net benefit	271 661		70 474	
Value / cost ratio	2.06		1.24	
Partial budget analysis for fertilizer use				
Treatment related costs *	124 016		109 395	
Gross added product	354 723		168 117	
Added net benefit	230 707		58 722	
Value / cost ratio	2.86		1.51	

5 * Includes costs of fertilizers and their application, as well as the costs for threshing, harvesting
 6 and bagging of the yield increase caused by fertilizer use

7

1 **CAPTIONS OF FIGURES**

2

3 **Figure 1.** Average daily minimum and maximum air temperature between 1969 and 1979 at
4 Fada N’Gourma, the weather station closest to the irrigation scheme at Bagré, Burkina Faso.

5

6 **Figure 2.** Average spikelet sterility and crop growth duration of FKR 19 (TOX 728-1) and
7 FKR 14 (4418), simulated with RIDEV using weather data from Fada N’Gourma and the
8 years 1969-1979.

9

10 **Figure 3.** Actual timing of farmers' practice compared to simulated optimal timing of crop
11 management interventions according to RIDEV in days after sowing (DAS). Urea application
12 recommendations are given for early tillering (ET), panicle initiation (PI) and booting (B).
13 Results are separated for the 1999 dry season (a) and the 2000 wet season (b).

14

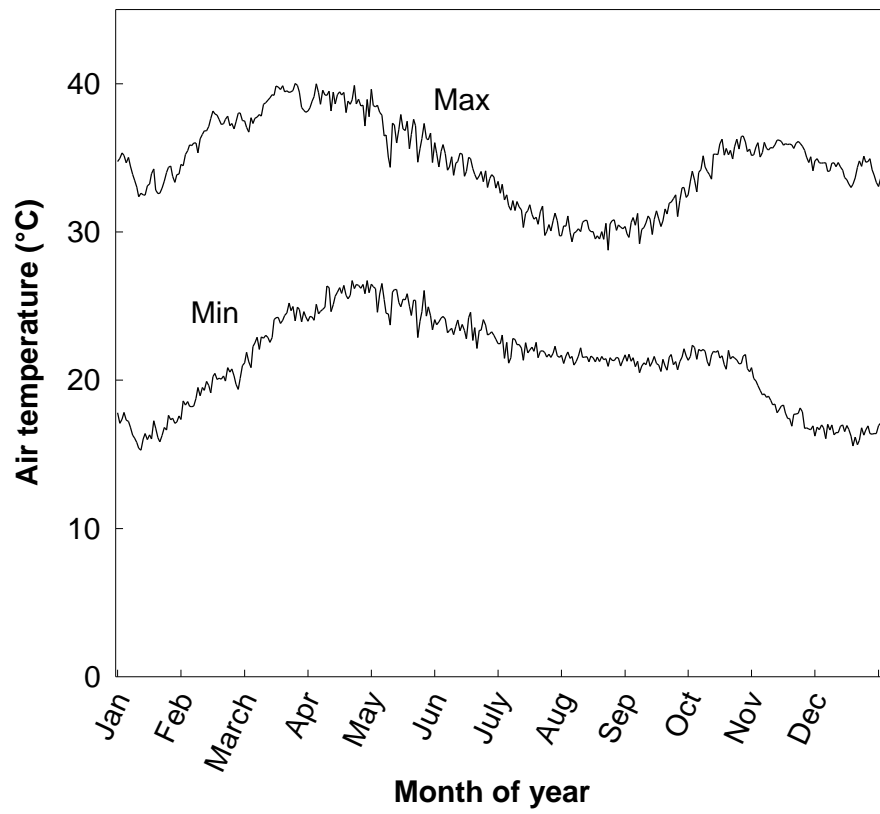
15 **Figure 4.** Yield gaps between best farmers yield, farmers average yield and yields without
16 fertilizer application (T_0 treatment). Results are presented separately for the 1999 dry season
17 and the 2000 wet season.

18

19 **Figure 5.** Characteristic features of indigenous and applied nitrogen in farmers’ fields during
20 the 2000 wet season in the Bagré irrigation scheme (Nimatoulaye, Burkina Faso). The
21 relation between grain yield and N-uptake in fertilized (T_F) and unfertilised plots (T_0) is
22 shown in Figure 5a. Shown are also the relation between farmers’ yield and N-dose applied
23 (5b), the recovery rate of applied fertilizer N (5c), and the relation between N absorbed in
24 fertilized (T_F) and unfertilised plots (T_0) (5d).

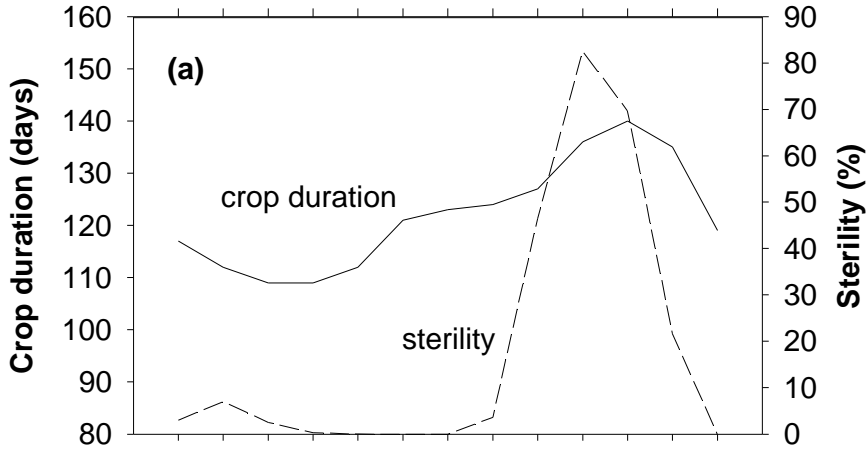
25

26 **Figure 6.** Cumulative distribution functions of net returns to fertilizers for farmers in
27 Nimatoulaye during the 1999 dry season and 2000 wet season. The vertical axis shows the
28 cumulative probability of having the corresponding level of returns.



Number of years with spikelet sterility > 20%

0 0 0 0 0 0 0 1 8 10 9 6 0



0 0 0 0 0 0 0 4 10 9 9 2 0

