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Economic analysis and food security contribution of supplemental irrigation and farm ponds: evidence from northern Burkina Faso

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Abstract

Background: Dry spells are serious obstacles to rainfed agriculture in Sahelian countries. Various water harvesting techniques are used by farmers to reduce the impact of climate variability, but are not sufficient in the case of a prolonged drought lasting 2–3 weeks. The farmers believe supplemental irrigation is a good way to adapt rainfed agriculture to dry spells. In this study, we evaluated the food contribution and profitability of supplemental irrigation of rainfed crops comparing various farm ponds that collect runoff water from the surrounding landscape.

Methods: We analyzed the contribution of supplemental irrigation to food security and compared the profitability of different types of ponds constructed by farmers in northern Burkina Faso. Human cereal requirement was used as indicators to analyze the contribution of supplemental irrigation to food security. The criteria for analyzing the profitability of the selected ponds were gross margin (GM), net present value (NPV), internal rate of return (IRR) and payback period (PBP).

Results: Our results show that the additional yield of corn obtained with supplemental irrigation makes it possible to meet the monthly cereal needs of at least 17 people and generates an additional GM of FCFA 178,483 (US\$ 309.26) compared to no irrigation. The estimate of the NPV, from IRR and PBP showed that the profitability of supplemental irrigation in 15 agricultural seasons varies between the type of ponds constructed.

Conclusions: Given the up-front cost and the farmers' lack of resources, the ponds require a subsidy or a credit policy to facilitate the adoption of supplemental irrigation in Sahelian countries. However, the irrigation strategies to optimize agricultural income remain a field of research to be explored.

Keywords: Cereal need, Dry spells, Profitability, Rainfed agriculture, Runoff water

Background

In the Sahel countries, the agricultural sector plays a fundamental role in the national economies and food security, but is highly vulnerable to climate variability and

change. The irregular rainfall distribution is a serious obstacle to rainfed agriculture. Various water harvesting techniques (zaï or tassa, stone rows, halfmoon, filtering dykes, bunds, mulching, etc.) are used by farmers to reduce the impact of the variability, but are not sufficient in the case of a prolonged drought lasting 2–3 weeks [1, 2]. The farmers' vulnerability to the Sahelian climate and food insecurity increased at the end of the twentieth

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century due to an almost 30% reduction in rainfall concomitant with a population increase [3, 4]. The dry spells continues to affect agricultural productivity, thereby reducing food security which exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life [5]. Sufficiency of food is focused on the availability of an adequate quantity and quality of food; physical and economic access looks at households and individuals having access to enough food; the security dimension is about food utilization by the body, food safety, risks, shocks, vulnerability, and trade-offs, while the time dimension looks at the stability of food availability, access, and utilization.

According to [6], between 720 and 811 million people in the world faced food insecurity. Considering the middle of the projected range (768 million), 118 million more people were facing hunger in 2020 than in 2019, with estimates ranging from 70 to 161 million. The numbers show enduring and troubling regional inequalities. About one in five people (21 percent of the population) was facing hunger in Africa in 2020—more than double the proportion of any other region. This represents an increase of 3 percentage points in 1 year. Sub-Saharan Africa is among the regions most affected by food insecurity, being home to 60% of the world's food insecure people [5]. In Burkina Faso, food insecurity affects more than 70% of the population [7, 8]. According to [9], the food insecurity affected 89.5% of households in the northern region. Therefore, farmers, researchers, governments and global development community are looking for innovative pathways to stabilize or increase rainfed agricultural production and food supply [10].

Supplemental irrigation appears to be a promising way to adapt rainfed agriculture to climate variability and improve agriculture productivity [11–13]. Indeed, theoretical calculations already highlighted the possibility of increasing the productivity of rainfed crops through supplemental irrigation [14–16]. According to [17, 18], if supplemental irrigation were applied to all rainfed cropland, global cereal production could be increased by 35%, the largest potential being in Africa and Asia. Households that grow rainfed crops are willing to practice supplemental irrigation using rainwater harvested in ponds in future agricultural seasons [19, 20]. These households believe supplemental irrigation is a good way to adapt rainfed agriculture to dry spells and improve food security. Supplemental irrigation is currently being scaled up in Sahelian Africa through several agricultural development programs, yet its profitability and food security contribution are not yet formally known [12, 21]. The recent studies focused only on the impact of

supplemental irrigation on yields and the socioeconomic factors of farmers' willingness to adopt it without assessing the costs of ponds and addressing the food security [15, 19, 20]. Practicing supplemental irrigation requires investment upstream for the construction of runoff collection ponds and the purchase of dewatering equipment [22].

The overall aim of this article is to assess the economic profitability of supplemental irrigation using runoff collection ponds in Burkina Faso. The specific objectives are to analyze the contribution of supplemental irrigation to food security and to compare the profitability of different types of ponds dug by the householders on their farms.

According to the literature, numerous definitions and indicators of food security, which, while helping to improve food security knowledge, increase the difficulty in measuring the concept consistently [23–25]. The most widely used and validated food security indicators that dominate the food security measurement debate are focus on: household food insecurity access scale, coping strategy index and dietary diversity score [26, 27]. These indicators offer little consensus on what food security should be [25, 27, 28].

In Sahelian countries, food security largely depends on national cereal and fodder production because more than 80% people have very limited access to imported food [11, 29]. Therefore, governments use cereal and fodder needs as indicators of food security in planning and evaluating results of agricultural campaigns following norms of Permanent Inter-states Committee for Drought Control in the Sahel which has proposed consumption standards by country, considering the habits and diversification of food consumption [8]. This approach offers a much finer analysis of the food situation than in the usual approaches [30]. In line with [8], we use cereal and fodder requirements as indicators to analyze the contribution of supplemental irrigation to food security. The criteria for analyzing the profitability of the selected runoff collection ponds are net margin, net present value, the internal rate of return and the payback period [31].

The remainder of the paper is organized as follows. After describing the materials and methods, we present the results and discussions. The conclusions including some policy implications and research limits are provided in the last section.

Materials and methods

Supplemental irrigation system

Supplemental irrigation consists of supplying water to crops during the long dry spells that occur during the rainy season, using water stored in a small pond constructed near the field concerned [3, 4]. Supplemental irrigation makes it possible to irrigate a portion of

farmland dedicated to intensive cultivation. It is based on four principles: (i) the construction of the pond by the farmer and his family with possible support from neighbors; (ii) the collection of runoff water from the start of the rainy season; (iii) the choice of crop; and (iv) practicing irrigation during dry spells in the rainy season. The irrigation equipment proposed here is the pedal pump (Fig. 1).

Study area

Supplemental irrigation was tested in the provinces of Yatenga and Bam in northern Burkina Faso in this study. The region is characterized by a long dry season from October to May and a short rainy season from June to September. Annual average rainfall varies between 500 and 600 mm. It is particularly irregular and unevenly distributed.

Eleven pilot producers, six producers in Bam province and five in Yatenga province, were selected to practice supplemental irrigation during three rainy seasons (2013–2016) as part of a pilot project supported by the International Development Research Centre (IDRC). The criteria for choosing the producers were mastery of farming techniques, the availability of family labor and access to at least 0.25 ha of farmland for supplemental irrigation, and the absence of wells or watercourses in the vicinity of the farm.

Each farm selected an experimental plot of 0.25 ha and a control plot of 0.25 ha, where the *barka* corn variety

(80 days) was sown. Both the plots belong to the same farmer. Some vegetable crops (local eggplant, pepper) or tobacco were also sown after the corn was harvested in the experimental plot. Seeds, fertilizers and a pedal pump were supplied to each pilot producer for experimentation (Fig. 2).

Food security analysis

The contribution of irrigation to food security was estimated based on human consumption of cereals and animal consumption of dry matter (fodder). In Burkina Faso, annual consumption of cereals is estimated to be an average of 190 kg/person, or 0.53 kg/day [8]. Consumption of dry matter by cattle is evaluated at 5.3 kg/day per head of cattle (0.85 Tropical Cattle Units) and 1 kg/day per sheep or goat [32].

The estimated number of additional people (N) that can be fed from the yield obtained from supplemental irrigation in 1 month (30 days) is given by the following formula:

$$N = \frac{Pdt_{PE} - Pdt_{PT}}{0.53 \times 30}, \tag{1}$$

where Pdt_{PE} = yield of the experimental plot (kg) and Pdt_{PT} = yield of the control plot (kg). A Student's *T* test was used to compare the average returns of yields.

The number of additional sheep or goats (*A*) that can be fed from the yield resulting from supplemental irrigation in 1 month (30 days) is given by the following formula:

$$A = \frac{MS_{PE} - MS_{PT}}{5.3 \times 30}, \tag{2}$$

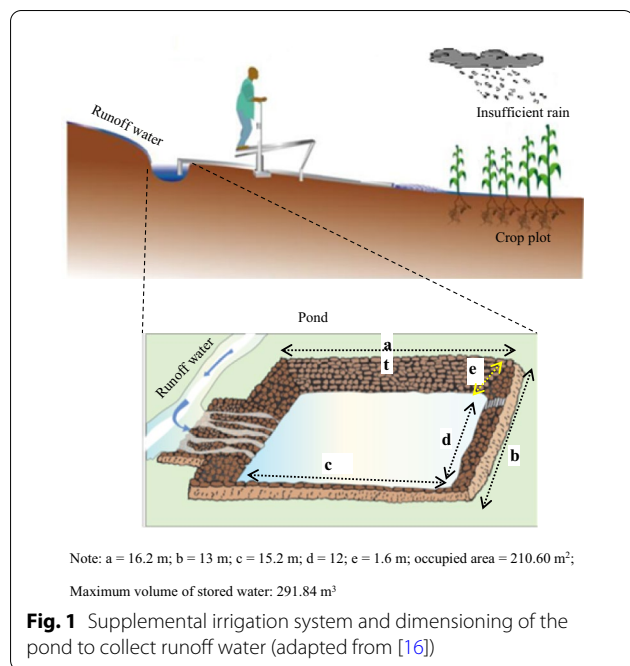
where MS_{PE} = dry matter yield in the experimental plot (kg) and MS_{PT} = dry matter yield in the control plot (kg).

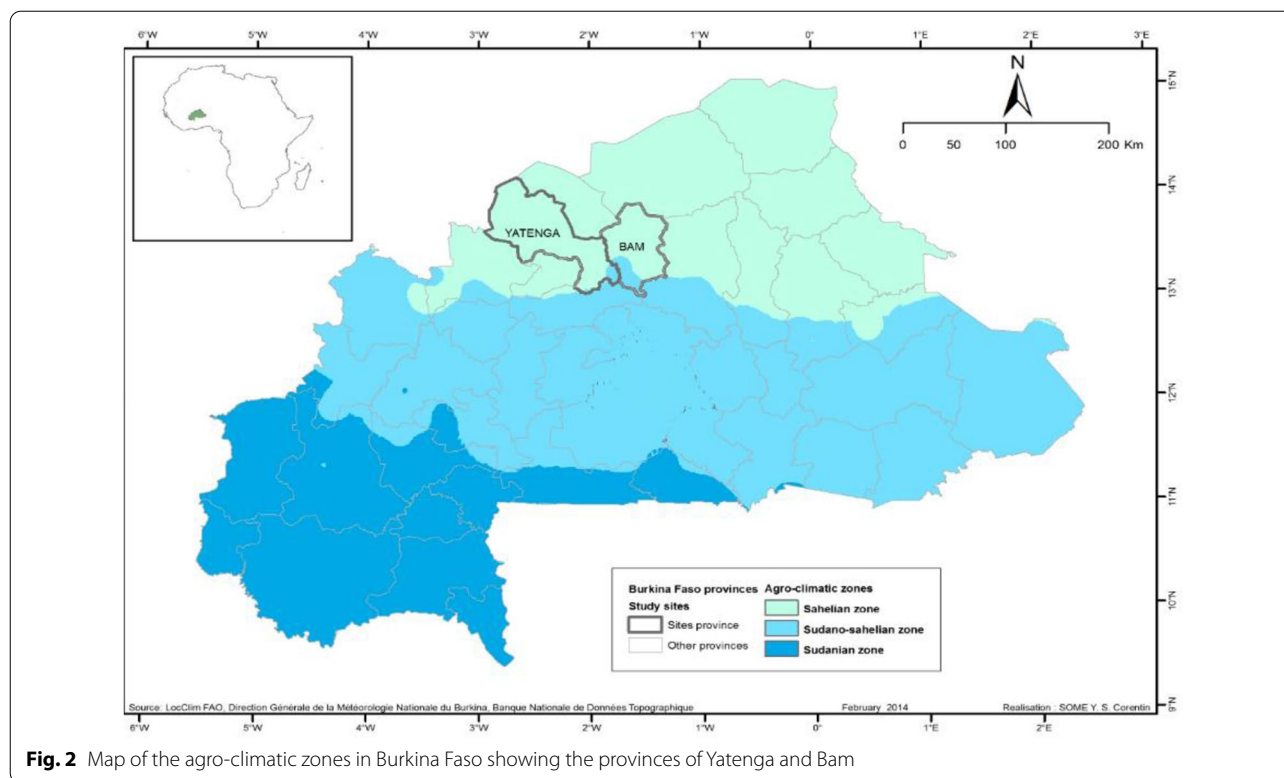
Profitability assessment

The gross margin (GM) of the experimental plots was estimated as the difference between the gross product (GP) and the input cost (IC) [31]:

$$GM = GP - IC. \tag{3}$$

GB was obtained by multiplying the quantity of corn grain and corn fodder by their market price. Purchased inputs for farmers included fertilizers (nitrogen, phosphorus and potassium: 200 kg/ha; urea: 50 kg/ha) and improved maize seeds (20 kg/ha). The cost of each input was estimated as the quantity of an input multiplied by its purchase price. Hired labor has not been employed for any agricultural activities. The difference between GM of the experimental plot and the control plot represents





the monetary profit gained by practicing supplemental irrigation.

The net profit margin (NPM) was obtained by deducting input costs (IC) and fixed costs (FC) from the gross product (GP) or by deducting the fixed costs (FC) from the gross margin (GM). Annual FCs include annual depreciation of the pond and of the pump. A straight-line depreciation rate was used. The life span of the pond was set at 15 years and that of the irrigation equipment at 5 years. The farmers’ family labor ensured the land preparation, plowing, sowing and harvesting in both plots. The cost of farmers’ labor is not included in the FC.

$$NPM = GP - IC - FC = GM - FC. \tag{4}$$

If the net margin is positive, it is concluded that the gross product covers all the fixed costs and that the agricultural production activity is economically attractive. On the other hand, if the net margin is negative, then the gross product cannot cover the costs. In this case, the production is not economically attractive.

To analyze the profitability of the supplemental irrigation system, we considered the average production of corn in the three agricultural seasons. The criteria used for the analysis were net present value (NPV), internal rate of return (IRR) and payback period (PBP) [33].

The NPV was evaluated as the sum of all the discounted benefits obtained by the difference between the target

product and the cost of the inputs and the fixed cost of the supplemental irrigation equipment. These charges are linked to the construction of the pond and the purchase of dewatering equipment. Formally, at the end of 15 crop years (agricultural campaigns), the NPV is given by the following expression:

$$NPV = \sum_{t=1}^{15} \frac{GP_t - IC_t - FC_t}{(1 + r)^t}, \tag{5}$$

where t is the crop year and r is the discount rate estimated to be 12.5% according to the credit institutions from which farmers can sometimes obtain credit. Note that when planning at a 15-year horizon, the pump will have to be renewed three times given that its life span is fixed at 5 years. When the NPV is positive, the investment is deemed to be economically profitable, and the project deserves to be undertaken. On the other hand, if it is negative, the investment is not profitable and supplemental irrigation should not be practiced, as it will result in a loss.

The IRR was assimilated in the rate that cancels the NPV. It is determined by the following equation:

$$\sum_{t=0}^{15} \frac{GP_t - FC_t - IC_t}{(1 + r)^t} = 0. \tag{6}$$

The investment required for the implementation of supplemental irrigation devices is appropriate when the IRR is higher than the discount rate; otherwise, there is no need to invest.

The PBP is the time d necessary for the net benefits to balance the investment costs required to acquire the supplemental irrigation system. It is formulated according to the expression:

$$\sum_{t=0}^d GP_t = \sum_{t=0}^d (CI_t + FC_t). \tag{7}$$

The profitability of supplemental irrigation system depends on the type of pond. Note that the cost of purchasing the supplemental irrigation system includes the cost of household labor in the form of a salary.

Results

Yield assessment

As shown in Fig. 3a, the average yields of maize obtained at the end of the 2013–2014 cropping year were estimated at 2.46 T/ha in the experimental plot and 1.71 T/ha in the control plot. In the 2014–2015 campaign, yields were evaluated at 1.88 T/ha and 0.92 T/ha, respectively, in the experimental and control plot. In the 2015–2016 cropping year, the yields obtained from the experimental plot were 2.76 T/ha versus 1.78 T/ha from the control plot. The Student’s T test revealed a significant difference between the average yields of the experimental plot and the control plot at the end of the 2013–2014 cropping year ($t=4.134$; $p=0.003$), 2014–2015 ($t=6.656$; $p=0.000$) and 2015–2016 ($t=4.844$; $p=0.001$). The difference in average maize yields on the experimental plots between years is related to the variation of intervals and doses of supplemental irrigation practiced by farmers. On the other hand, on the control plots, this difference

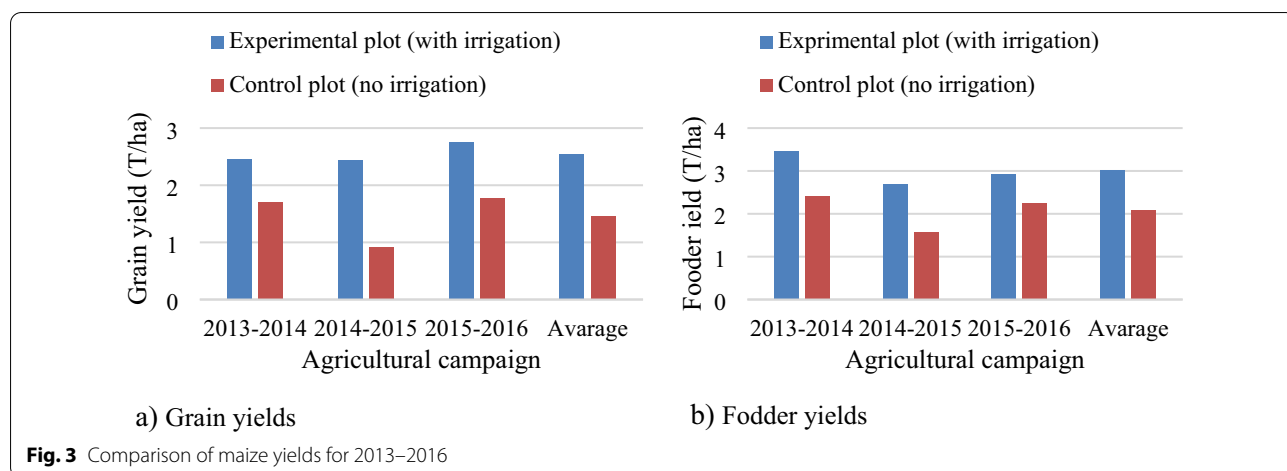
in yield is explained by variation in the duration of dry spells during campaign seasons.

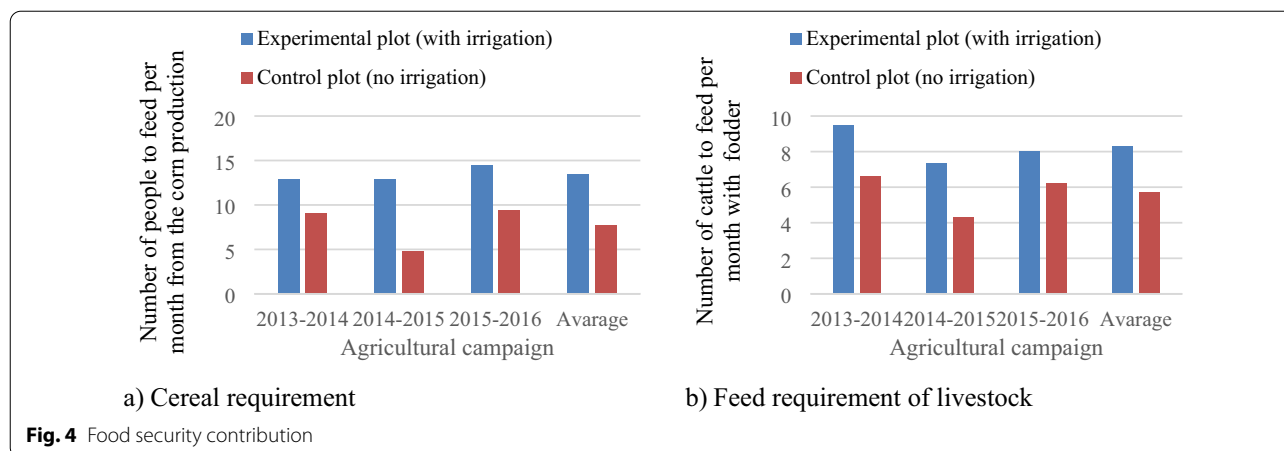
Yields of fodder obtained from the experimental plot were higher than yields obtained from the control plot (Fig. 3b). The average yields obtained in the 2013–2014 cropping year were estimated at 3.47 T/ha in the experimental plot and 2.42 in the control plot. In 2014–2015, the experimental plot and the control plot produced 2.69 and 1.58 T/ha, respectively. In the 2015–2016 campaign, yields from the experimental plot and the control plot were 2.93 T/ha and 2.26 T/ha, respectively. Statistical analyses revealed a significant difference between the yields in the experimental plot and in the control plot after the 2013–2014 cropping year ($t=3.405$; $p=0.006$), 2014–2015 ($t=3.942$; $p=0.002$) and 2015–2016 ($t=3.536$; $p=0.008$).

Contribution to food security

The contribution of corn production to food security varied with the experimental plot (Fig. 4a). The average yield of corn from the experimental and control plots in the 2013–2014 campaign covered the cereal needs of, respectively, 39 and 27 people for 1 month. Those of the experimental and control plots in 2014–2015 satisfied the cereal needs of, respectively, 38 and 14 people. In the 2015–2016 campaign, the corn yield from the experimental plot covered the cereal needs of 43 people and those of the control plot, 28 people. It thus appears that the surplus yields obtained from the experimental plot in 2013–2014, 2014–2015 and 2015–2016 would feed between 12 and 24 additional people in the households per month compared to the control plot. These surpluses can meet the cereal needs of the average household of five people in the study area for at least 3 months.

The number of cattle fed with fodder obtained from the experimental plot in 1 month was estimated at nine in





2014–2015, seven in 2014–2015 and eight in 2015–2016 (Fig. 4b). The number of cattle fed fodder obtained from the control plot was estimated at seven in 2013–2014, four in 2014–2015 and six in 2015–2016. Thus, compared to the control plot, the number of additional cattle fed with the fodder from the experimental plot was two in 2013–2014, three in 2014–2015 and two in 2015–2016. This additional number shows that the practice of supplemental irrigation on corn is advantageous for livestock.

Gross margin

The gross margin obtained from average corn yields in the 2013 to 2016 agricultural campaigns differed between the experimental plot and control plot (Table 1). The GM was evaluated at FCFA 77,634 (US\$ 134.57) for the experimental plot and at FCFA 50,632 (US\$ 87.76) for the control plot at the end of the 2013–2014 campaign. The GM of the experimental and control plot in the 2014–2015 campaign was estimated at, respectively, FCFA 23,455 (US\$ 40.66) and FCFA 72,263 (US\$ 125.26). In 2015–2016, the GM was estimated at FCFA 82,513 (US\$ 143.03) for the experimental plot and FCFA 51,375 (US\$ 89.05) for the control plot.

Supplemental irrigation of rainfed corn produced a surplus of FCFA 27,002 (US\$ 46.80) in 2013–2014, FCFA 48,809 (US\$ 84.60) in 2014–2015, and FCFA 31,138 (US\$ 53.97) in 2015–2016. The surplus generated in 2014–2015 was higher than in 2013–2014 and 2015–2016. The average increase in GM was FCFA 35,649 (US\$ 61.79) per campaign. Since input costs remained similar between years, the difference can be explained by the differences in grain and forage yield in the three seasons.

Many pilot producers sowed a second crop after corn (eggplant, tobacco, pepper, sesame, okra, cowpea, soy) using the water collected in the ponds during the rainy season (Table 2). The released average GM was evaluated

at FCFA 19,178 (US\$ 33.24) in 2013–2014, FCFA 17,450 (US\$ 30.25) in 2014–2015, and FCFA 194,550 (US\$ 337.23) in 2015–2016. The cultivation of tobacco by some pilot farmers explains the significant increase in GM in the 2015–2016 campaign.

Taking corn and secondary crops into account, the difference between the GM of the experimental and control plots was estimated at FCFA 46,180 (US\$ 80.05) in the 2013–2014 agricultural campaign, FCFA 115,067 (US\$ 199.45) in 2014–2015 and FCFA 256,825 (US\$ 445.17) in 2015–2016 (Fig. 5). The average GM was estimated at FCFA 178,423 (US\$ 309.26) per campaign. These results confirm that supplemental irrigation of rainfed crops could be a profitable way to mitigate the effects of climate variability and climate change in the Sahel.

Net profit margin

Cost of building the ponds

All the ponds were built by the farmers' families and volunteer neighbors. The equipment used for the construction of these ponds included picks, crowbars, shovels, wheelbarrows, wire mesh plus rubble and gravel. Cement, clay and tarpaulin for waterproofing was only needed in some ponds whose underlying soils were too porous. The type of waterproofing material explains the difference in the cost of the ponds. Depending on the investment cost, there are four categories of ponds (Table 3):

Ponds whose bottom and walls are not waterproofed.

This type of pond was constructed in clayey or lateritic soils (Fig. 5a, b) characterized by low seepage. After excavation, the walls and bottom of the pond received no coating since the type of soil prevents leakage of the collected runoff water. The investment cost of this type of pond was evaluated at FCFA

Table 1 Gross margins in the 0.25 ha corn cultivation plot

Item	2013–2014 campaign		2014–2015 campaign		2015–2016 campaign		Average	
	Control (no irrigation)	Exp. (with irrigation)	Control (no irrigation)	Exp. (with irrigation)	Control (no irrigation)	Exp. (with irrigation)	Control (no irrigation)	Exp. (with irrigation)
Grain yield (kg)	428	614	229	609	444	689	367	637
Grain sales price (FCFA/kg)	110	110	110	110	110	110	110	110
Fodder yield (kg)	605	866	394	672	565	733	521	757
Sale price of fodder (FCFA/kg)	25	25	25	25	25	25	25	25
Gross product (FCFA)	62,195	89,197	35,017	83,826	62,938	94,075	53,383	89,033
NPK (FCFA)	5,750	5,750	5,750	5,750	5,750	5,750	5,750	5,750
Urea (FCFA)	4,313	4,313	4,313	4,313	4,313	4,313	4,313	4,313
Seeds (FCFA)	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Cost of inputs (FCFA)	11,563	11,563	11,563	11,563	11,563	11,563	11,563	11,563
Gross margin (FCFA)	50,632	77,634	23,455	72,263	51,375	82,513	41,821	77,470
Gross margin difference (FCFA)	27,002		48,809		31,138		35,649	

Table 2 Gross margins of secondary crops under supplemental irrigation

Secondary crops	Gross margin (FCFA)			
	2013–2014 Campaign	2014–2015 campaign	2015–2016 campaign	Average
Eggplant	5850	2000	4050	16,200
Tobacco		8900	130,000	69,450
Pepper	4928	1500	6800	4409
Sesame		800		800
Okra		3250	14,000	8625
Cowpea	8400	1000		4700
Soy	–	–	3000	3000
Gross margin (F CFA)	19,178	17,450	194,550	77,059

784,900 (US\$ 1,360.52) when the workforce is paid wages. When the opportunity cost of the plot and annual maintenance were added, the cost of the pond reached FCFA 802,900 (US\$ 1,391.72).

a pond with a waterproof base of clay and cemented waterproof walls (Fig. 5c). This type of pond was constructed on clayey soil characterized by more seepage than in clayey or lateritic soils. The seepage is mainly vertical, i.e. through the bottom of the pond. To limit it, the bottom of the pond is coated with clay transported to the site. Assuming household labor is paid, the construction cost was evaluated at FCFA 922,900 (US\$ 1599.73). When the opportunity cost of the land and the annual maintenance of the pond were added, the total cost was FCFA 940,900 (US\$ 1630.93). It is the cost of cement and clay for waterproofing the walls and the bottom that increase the cost of this type of pond.

a pond with a tarpaulin bottom and waterproofed cement walls (Fig. 5d). This type of pond was con-

structed in sandy loam soils characterized by a higher seepage rate. To limit this seepage, cement and a tarpaulin were purchased to coat the walls and the bottom of the pond. The cost was evaluated at FCFA 1,710,900 (US\$ 2964.06) when the workforce is paid. When the opportunity cost of the land and the annual maintenance of the pond were added, the total cost was FCFA 1,728,900 (US\$ 2996.82).

a pond with both the bottom and walls waterproofed with a tarpaulin (Fig. 5e). This type of pond was constructed in sandy soils with a high rate of seepage. To avoid this heavy seepage, a tarpaulin covered both the walls and the bottom of the pond. Its construction required an investment of FCFA 2,191,900 (US\$ 3799.37) assuming that the labor for the excavation is paid in cash. When the opportunity cost of the land and the annual maintenance were added, the cost was evaluated at FCFA 2, 201, 900 (US\$ 3816.70). This pond is the most expensive (Fig. 6).

Cost of irrigation equipment

The pump kit includes a foot pump, bearings, valves, a strainer, a cup, spare parts and suction and discharge pipes (Table 4). The cost of the kit is estimated at FCFA 139,476 (US\$ 241.76). The purchase of the foot pump and suction hoses represents 70% of the total acquisition cost. The pump operates on human energy using two pedals via a suction and delivery system (Fig. 5f). It can lift water up to 7 m high and discharge it at a distance of 200 m on flat ground. Its average flow rate is 3300 L per hour depending on the intensity of pedaling. It can irrigate 2500 m² (0.25 ha) in 2 h.

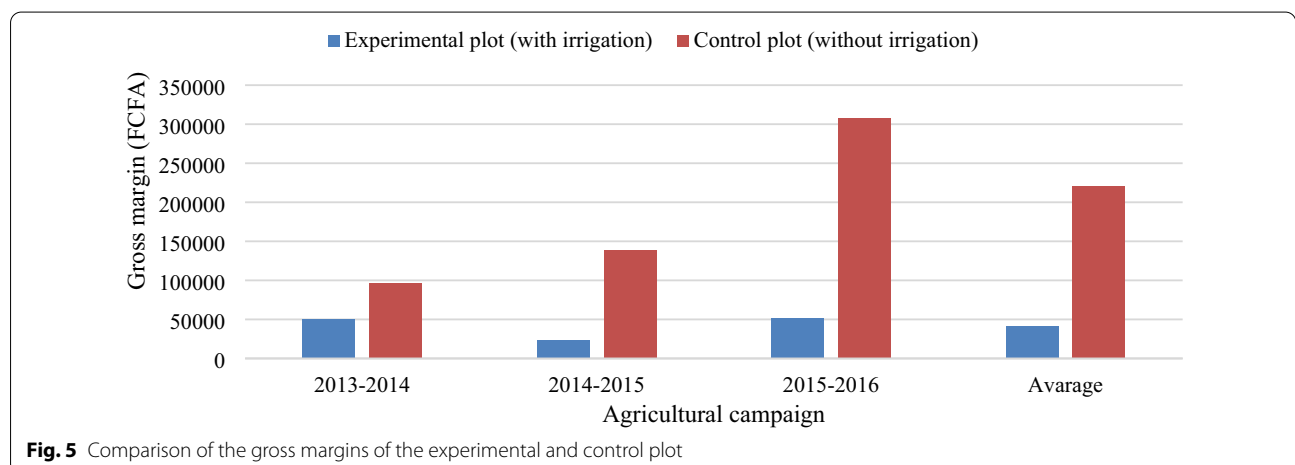


Fig. 5 Comparison of the gross margins of the experimental and control plot

Table 3 Estimated cost of the ponds

Item	Pond 1: bottom and walls not waterproofed			Pond 2: bottom waterproofed with clay and cemented walls			Pond 3: Tarpaulin bottom and cemented walls			Pond 4: Tarpaulin waterproofed bottom and walls		
	Quantity	Unit price	Amount (FCFA)	Quantity	Unit price	Amount (FCFA)	Quantity	Unit price	Amount (FCFA)	Quantity	Unit price	Amount (FCFA)
Crowbar	5	8000	40,000	5	8000	40,000	5	8000	40,000	5	8000	40,000
Pickaxe	5	2000	10,000	5	2000	10,000	5	2000	10,000	5	2000	10,000
Shovel	5	1500	7500	5	1500	7500	5	1500	7500	5	1500	7500
Wheelbarrow	3	20,000	60,000	3	20,000	60,000	3	20,000	60,000	3	20,000	60,000
Gloves (price per pair)	15	1500	22,500	15	1500	22,500	15	1500	22,500	15	1500	22,500
Annual equipment maintenance		Flat rate	25,000		Flat rate	25,000		Flat rate	25,000		Flat rate	25,000
Reinforcement of wheelbarrows		Flat rate	7500		Flat rate	7500		Flat rate	7500		Flat rate	7500
<i>Cost of construction material</i>			172,500			172,500			172,500			172,500
Excavation (m ³)		1000	283,000		1000	283,000		1000	283,000		1000	283,000
Talutage			9000			9000			9000			9000
Rubble transport		Flat rate	120,000		Flat rate	120,000		Flat rate	120,000		Flat rate	120,000
Cost of gravel transport		Flat rate	60,000		Flat rate	60,000		Flat rate	60,000		Flat rate	60,000
Clay transport			0			30,000			0			0
Cost of labor		Flat rate	0		Flat rate	25,000		Flat rate	50,000		Flat rate	0
Stabilization		Flat rate	10,000		Flat rate	15,000		Flat rate	30,000		Flat rate	9000
<i>Construction cost of the pond (+ cost of equipment)</i>			654,500			714,500			724,500			653,500
Wire mesh		Flat rate	100,000		Flat rate	100,000		Flat rate	100,000		Flat rate	100,000
Transport of the mesh to the site		0	10,000		0	10,000		0	10,000		0	10,000
Labor needed to install wire mesh		Flat rate	20,400		Flat rate	20,400		Flat rate	20,400		Flat rate	20,400
<i>Total cost</i>			130,400			130,400			130,400			130,400
Tarpaulin	0	0	0		0	0	175	4000	700,000	350	4000	1,400,000
Cement	0	6500	0	24	6500	78,000	24	6500	156,000	0	6500	0
<i>Cost of waterproofing</i>			0			78,000			856,000			1,400,000
Total cost of pond			784,900			922,900			1,710,900			2,183,900
Opportunity cost of 1 ha of land		Flat rate	8000		200,000	8000		200,000	8000		200,000	8000
Annual pond maintenance		Flat rate	10,000			10,000		Flat rate	10,000		Flat rate	10,000
Total cost of acquiring the pond + opportunity cost of 1 ha of land			792,900			930,900			1,718,900			2,191,900

Table 3 (continued)

Item	Pond 1: bottom and walls not waterproofed		Pond 2: bottom waterproofed with clay and cemented walls		Pond 3: Tarpaulin bottom and cemented walls		Pond 4: Tarpaulin waterproofed bottom and walls	
	Quantity	Unit price	Quantity	Unit price	Quantity	Unit price	Quantity	Unit price
		Amount (FCFA)		Amount (FCFA)		Amount (FCFA)		Amount (FCFA)
Total cost of construction acquisition + opportunity cost of 1 ha of land + maintenance		802,900		940,900		1,728,900		2,201,900



a) Pond with bottom and un-waterproofed walls on clay soil in Bam province



b) Pond with bottom and un-waterproofed walls on lateritic soil in Yatenga province



c) Pond in impermeable clay with waterproofed cement walls in Bam province



d) Pond with covered bottom and waterproofed cement walls in Yatenga province



e) Pond with bottom and walls waterproofed with a tarpaulin in sandy soil in Bam province



f) Piloting supplemental irrigation using a pedal pump in Bam province

Fig. 6 Types of ponds and irrigation equipment

Analysis of the profit margin

For supplemental irrigation, the fixed costs are determined by the sum of the annual depreciation of each type of pond and the dewatering equipment. The annuity is obtained by multiplying the cost of each type of pond or

dewatering equipment by a linear depreciation rate. The linear depreciation rate is calculated by dividing 100 by the expected life of each pond or dewatering equipment (Table 5). The life span was estimated at 15 years for each pond and at 5 years for the dewatering equipment.

Table 4 Cost of dewatering equipment

Item	Quantity	Unit price (FCFA)	Amount (FCFA)
Foot pump	1	49,500	49,500
26 m elbows	1	30,00	3,000
32 m suction hose	1	39,00	3,900
26 m discharge hose	1	562,50	56,250
Pedal bearings	1	300	300
Tilt bearings	1	300	300
Leak valve	1	200	200
Strainer	1	4,000	4,000
Cup	1	500	500
Discharge/suction valve	1	250	250
VAT (18%)	1	21,276	21,276
Cost of irrigation equipment (FCFA)	–	–	139,476

Table 5 Estimated depreciation of ponds and dewatering equipment

Item	Cost of construction (FCFA)	Estimated life	Depreciation rate	Annuity (FCFA)
Pond 1	784,900	15	6.67%	52,327
Pond 2	922,900	15	6.67%	61,527
Pond 3	1,710,900	15	6.67%	114,060
Pond 4	2,191,900	15	6.67%	145,593
Pedal pump and accessories	139,476	5	20%	27,895

The analysis shows that the practicing supplemental irrigation from a pond with un-waterproofed walls and from a pond with only a waterproof clay bottom and cemented walls guarantee a positive net margin (Table 6). In other words, the gross product covers the fixed costs, and the practice of supplemental irrigation is thus profitable at a 15-year horizon. Supplemental irrigation is not profitable using a pond with a bottom covered with tarpaulin and cemented walls or a pond with a both bottom and walls covered with tarpaulin since the net margin is negative. By comparing the ponds, the costs of waterproofing, transporting the clay to the site, stabilization and masonry explain the respective profitability of the different ponds. Apart for these items, the costs of the other components of the ponds are similar.

Analysis of profitability

When the bottom and walls are not waterproofed The NPV is positive from 5 to 15% discount rates and becomes negative from 20% (Table 7). The IRR is evaluated at 19.5% and the PBP at a 7-year horizon (Table 8). These results show that the practice of supplemental irrigation using a pond whose bottom and walls are not waterproofed is a viable innovation for agricultural

households, since the NPV is positive for a discount rate of up to 15%. This practice can be adopted since the IRR is higher than the fixed interest rate (12.5%) charged by banks in Burkina Faso. Ponds dug in clayish or lateritic soils thus tend to be profitable.

Ponds with a waterproofed clay bottom and waterproofed cement walls display a positive NPV of 5%–15%, an IRR estimated at 15.29% and a PBP of 7 years (Tables 7, 8). From the above, supplemental irrigation from a pond with a waterproofed clay bottom and cement walls proves to be a viable agricultural innovation that can be adopted by farmers, since the NPV is positive for a discount rate of between 5 and 15% and the IRR exceeds the interest rate charged by the banks (12.5%). The construction of ponds in clayey-loam soils is a profitable innovation for supplemental irrigation on rainfed corn over 15 agricultural campaigns.

Pond with a tarpaulin bottom and waterproofed cement walls: have a negative NPV from 5% discount, an IRR estimated at 4.5% and a PBP of 11 years (Tables 7, 8). These results suggest that practicing supplemental irrigation of rainfed corn using a pond built in sandy-silty is not a viable innovation beyond 5% discount or is only recommended insofar as the IRR is lower than that fixed

Table 6 Net margins of agricultural production in experimental plots

Designation	2013–2014		2014–2015		2015–2016		Average	
	Control	Exp	Control	Exp	Control	Exp	Control	Exp
Pond	50,632	96,812	23,455	89,713	51,375	277,063	41,821	184,654
1 + dewa- tering equipment	0	80,222	0	80,222	0	80,222	0	802,22
Pond	50,632	16,591	23,455	9,491	51,375	196,841	41,821	104,432
2 + dewa- tering equipment	0	89,422	0	89,422	0	89,422	0	89,422
Pond	50,632	7391	23,455	-79,931	51,375	107,419	41,821	15,011
3 + dewa- tering equipment	0	141,955	0	14,1955	0	141,955	0	141,955
Pond	50,632	-134,565	23,455	-221,886	51,375	-34,536	41,821	-126,945
3 + dewa- tering equipment	0	154,892	0	154,892	0	154,892	0	154,892
Pond	50,632	-252,263	23,455	-320,987	51,375	-133,638	41,821	-226,046
3 + dewa- tering equipment	0	154,892	0	154,892	0	154,892	0	154,892

Table 7 IRR and NPV of the supplemental irrigation system on 0.25 ha of corn

Pond categories	IRR	NPV						
		5%	10%	12.5%	15%	20%	25%	30%
Pond 1: bottom and walls not water-proofed	19.5%	756,390	369,568	238,707	21,141	−10,870	−144,460	−169,238
Pond 2: waterproof bottom of clay and cemented walls	15.2%	615,438	235,022	107,151	7,185	−13,4204	−224,408	−283,084
Pond 3: tarpaulin bottom and cemented walls	4.5%	−53,490	−432,456	−555,114	−648,053	−856,457	−842,827	−912,311
Pond 4: tarpaulin bottom and tarpaulin walls	1.1%	−476,956	−830,735	−942,964	−1,026,516	−1,134,116	−1,190,615	−1,216,555

Pond categories	NPV							
	35%	40%	45%	50%	55%	60%	65%	70%
Pond 1: bottom and walls not waterproofed	−213,954	−241,265	−261,305	−274,930	−283,992	−289,753	−293,092	−294,635
Pond 2: waterproof bottom of clay and cemented walls	−321,647	−346,979	−346,979	−373,597	−379,476	−382,253	−382,789	−381,693
Pond 3: tarpaulin bottom and cemented walls	−900,212	−906,392	−904,481	−902,578	−886,739	−876,355	−859,800	−844,816
Pond 4: tarpaulin bottom and tarpaulin walls	−1,223,763	−1,219,283	−1,207,443	−1,190,976	−117,1642	−1,150,601	−1,128,625	−1,106,236

by the banks (12.5%). It is profitable only after 15 years, corresponding to 15 agricultural seasons.

Pond with bottom and walls waterproofed with tarpaulin: The NPV is negative from 5% discount. The IRR is estimated at 1.1% and the PBP at 14 years (Tables 7, 8). Under these conditions, constructing this type of pond for supplemental irrigation in sandy soils is not profitable for agricultural households even after 15 rainfed corn campaigns. In fact, the NPV remained negative, and the IRR was lower than the bank interest rate (12.5%).

Discussion

The results obtained in the experimental plots underline the importance of supplemental irrigation to produce corn in the rainy season. Irrigation increases corn yields whatever the type of agricultural campaign. The increase in grain yields from the experimental plots compared to the control plots was 0.75 T/ha (43.47%) during the 2013–2014 campaign, 1.45 T/ha (166.32%) in 2014–2015 and 0.98 T/ha (55.21%) in 2015–2016. Supplemental irrigation can thus increase the average corn yield by 1.08 T/ha (averaged yields in the three agricultural seasons), or 88.34%. These results are comparable to those of other studies [34]. Supplemental irrigation at crops

critical growth stage increase more grain yield [17, 35]. In Morocco, Merabeta and Boutiba [36] showed that irrigation of rainfed wheat can produce grain yields of between 5.4 and 5.9 T/ha versus 1.5 and 3 T/ha for controls. This more than 100% increase in yields led the governments of Tunisia and Morocco to consider the respective developments of more than 23,000 and 30,000 ha of supplemental irrigation [37]. In Burkina Faso, Somé [15] showed that supplemental irrigation of sorghum increased sorghum yields by 10%–85% depending on the agricultural season. However, the results of the study by Barron and Okwach [38] in Kenya showed little impact of irrigation on corn yields when rainfall is fairly regularly distributed over the rainy season. From the analysis of previous studies, the impact of supplemental irrigation on yields depends on the importance of dry spells [22, 23, 36].

The increase in corn yields enabled by supplemental irrigation contributes to food security through increasing grain consumption by the households. It makes it possible to meet the monthly demand for 17 extra months for one person or covers the needs of five people for 3 months. These results suggest that supplemental irrigation relevance for food security in line with the norms of Permanent Inter-states Committee for Drought

Table 8 Discounted cash flows (FCFA)

Ponds categories	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Pond 1: bottom and walls not water-proofed	-739,722	-565,067	-390,413	-215,759	-41,104	-5,926	168,728	343,383	518,037	692,691	727,870	902,524	1,077,178	1,251,833	1,426,487
Pond 2: waterproof bottom of clay and cemented walls	-887,722	-713,067	-538,413	-363,759	-189,104	-15,3926	20,728	195,383	370,037	544,691	579,870	754,524	929,178	1,103,833	1,278,487
Pond 3: tarpaulin bottom and cemented walls	-1,675,722	-1,501,067	-1,326,413	-1,151,759	-97,7104	-941,926	-767,272	-592,617	-417,963	-243,309	-68,654	106,000	280,654	455,309	629,963
Pond 4: tarpaulin bottom and tarpaulin walls	-2,133,722	-1,949,067	-1,764,413	-1,579,759	-1,395,104	-1,349,926	-1,165,272	-980,617	-795,963	-611,309	-566,130	-381,476	-196,822	-1,2167	172,487

Control in the Sahel [8]. This is why Sahelian countries have adopted policies to popularize the practice of supplemental irrigation in order to reduce the effects of dry spells on agricultural production and improve food security [39, 40]. In these countries, supplemental irrigation helps farmers to adapt to climate change insofar as it makes it possible to increase agricultural production to meet the food needs of populations in dry years [17]. Farmers readily can adopt supplemental irrigation once they are convinced it reduces food insecurity [41]. But this practice is still rare in the Sahelian countries of West Africa. Research has long remained at the experimental stage in research stations [42, 43].

Investing in supplemental irrigation can have a significant impact on food security. However, this study found that supplemental irrigation from a farm pond is profitable under certain conditions. First, it depends on the types of soil and subsoil in which the pond is dug. Ponds dug in clay or lateritic and clay-silt soils are profitable over a period of 15 years, i.e., 15 agricultural campaigns. Panigrahi et al. [44] found this payback period to be acceptable for this type of hydraulic infrastructure. These authors showed that the ponds were economically profitable in 16 agricultural seasons. However, ponds constructed in sandy loam soils require some investments to reduce seepage. These investments include the purchase of cement or tarpaulin to waterproof the walls and the bottom of the pond. Given most Sahelian farmers' very limited access to credit, a credit program or a subsidy may be required for the construction of the ponds [17].

Conclusions

This study has shown that the extra corn yield obtained with supplemental irrigation from farm ponds can meet the monthly cereal needs of at least 17 people and generate an additional GM of FCFA 178,48 (US\$ 309.26) per campaign compared to rainfed crops. The estimate of the NPV, from IRR and PBP showed that the profitability of supplemental irrigation in 15 agricultural seasons depends on the type of ponds constructed. Here, we demonstrated the cost-effectiveness of supplemental irrigation for corn yields.

However, the study has some limitations. It does not take the dynamic nature of intensity and variability of precipitation over 15 years estimated period and risk of water-borne diseases and drowning (people and animals). Water productivity has not assessed to the extent that farmers have been allowed to practice irrigation when they observe water requirement for maize. For this, the irrigation doses could not be evaluated.

Moreover, a subsidy or credit policy will be needed for the construction of ponds to facilitate the adoption of supplemental irrigation in Burkina Faso. Irrigation strategies to optimize agricultural income remain a field of research to be explored. It seems necessary to support the up-front cost of the pond with a subsidy or a credit program in order to facilitate the adoption of supplemental irrigation on agricultural holdings. But in Sahelian countries, farmers have little access to credit. Experiences of food for work are now frequent and make it possible to mobilize labor for the construction of small agricultural infrastructures. The implementation of such a policy would stimulate the adoption of supplemental irrigation on a larger scale and help reduce food insecurity.

Abbreviations

GM: Gross margin; NPV: Net present value; IRR: Internal rate of return; PBP: Payback period.

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Authors' contributions

All authors provided substantial input into the manuscript, and SF processed, analyzed and interpreted the data and led the manuscript writing process. All authors read and approved the final manuscript.

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Competing interests

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