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Status of Fertilization and Crop Nutrition in Irrigated Agriculture in Sudan 2: Main Crops Consuming Fertilizers and the Role of Education in Optimizing Fertilizer Use

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Introduction

In Sudan, fertilizers are normally imported. However, the amounts utilized are very low when compared with other parts of the world, including in the Arabian region. Indeed in rainfed farming areas, whether mechanized or traditional, fertilizers are rarely used. The mean annual fertilizer use of N, P_2O_5 and K_2O is very low. According to the FAO (FAOSTAT 2010), in 2006 total consumption was of 44,000, 6,000 and 1,000 mt of urea, superphosphate (above 35 percent) and NPK complex, respectively, mostly used in irrigated agriculture (Table 1). In particular the application of potash is extremely low. Recently, however, a recommended use of 43 kg N ha^{-1} for sorghum has been approved by the Ministry of Agriculture but for only very localized areas.

Plans to increase fertilizer use are in progress as part of a major government agricultural development executive program for 2008-2011. Cropping areas are to be increased for crops such as sorghum, cotton, and wheat, and the cultivation of vegetables is to be greatly expanded. It is proposed that fertilizer supplies to the irrigated sector should increase considerably to just over 300,000 tonnes of urea and 50,000 tonnes of triple superphosphate (TSP) supplying all crops including sunflower, sugar cane and rice, besides those mentioned above. If all the areas planned for irrigation come under cultivation, annual fertilizer consumption in the future may increase up to 1,000,000 tonnes.

Table 1. Mean fertilizer nutrient consumption in the irrigated sector, 2000-02 (FAO, 2006).

Fertilizer	N	P_2O_5	K_2O
	'000 tonnes nutrients		
Urea	54.3		
Triple superphosphate		11.1	
Potassium chloride			3.8

This paper is the second on the issue of the status of fertilization and crop nutrition in Sudan. The first paper was published in the *e-ifc* 22, March 2010 (http://www.ipipotash.org/eifc/2010/22/2).

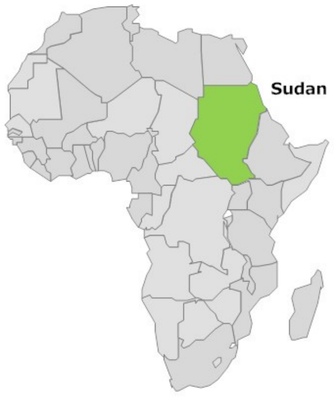
Research conducted with fertilizers on some of the main crops

Soil applied fertilizers

1. Cotton

Cotton is well known historically as an important crop in Sudan and is the major cash crop in the Gezira rotation. Besides export, the crop provides local textile factories with lint, and oil factories with cotton seed. The average yield of seed cotton has generally been low and a number of factors are suspected for this yield restriction including inadequate or inappropriate fertilization. Early investigations (Burhan, 1969, 1971; Burhan and Jackson, 1973; Burhan and Taha, 1974) examined crop response to single-nutrient fertilizers in long-term trials, over 18 seasons, in a 3-4 course rotation. These results showed that:

- The response to 190 kg ha^{-1} of urea was consistent and significant in all 18 seasons.
- There was an erratic positive response to P as TSP (in about 30 percent of the seasons).
- Response to K was rarely reported.



Sudan in the African continent.

The fertilization practice adopted in Gezira for cotton production was the application of 86 kg N ha^{-1} in the form of urea supplied 6 to 8 weeks after sowing followed by green ridging.

In all regions and treatments, the higher dose of fertilizers applied brought higher yields. However, evidence for the relatively poor response of cotton to urea fertilization alone, and sometimes resulting in a negative impact in terms of yield, provided the driving force for research testing of multi-nutrient fertilizers. Results from Ali *et al.* (2002; Table 2), show that when only N was applied, cotton yields were higher when N was supplied as Ammonium Sulfate

Table 2. Akala cotton yield (kg ha^{-1}) in three regions, 2001-2002 (Ali *et al.*, 2002).

Fertilizer	Dose	Gezira	Rahad	N. Halfa
		-------------*kg ha*$^{-1}$	--------------	
Urea	Regular	2,418	2,656	2,383
Urea	Double	2,758	3,098	2,928
AS	Regular	2,928	2,690	3,167
AS	Double	3,133	3,473	3,916
ASN	Regular	2,588	2,622	3,473
ASN	Double	3,269	3,609	3,643
NPK	Regular	2,928	2,622	3,367
NPK	Double	3,814	3,780	3,745

Ammonium Sulfate (AS), 21% N; Ammonium Sulfate Nitrate (ASN), 26% N; and Nitrophoska NPK. (18:18:5).

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Nitrate (ASN) or Ammonium Sulfate (AS) in comparison with urea. This finding may result from the greater availability of N in ASN and AS forms and the likelihood of the loss of N from urea by volatilization as ammonia (NH_3). The beneficial effect of the additional P and K on cotton yields over that of N alone is clearly evident from the results of Nitrophoska.

2. Wheat

Wheat production in Sudan started on fertile alluvial soils of the Nile in the Northern and Nile River States where winter is relatively longer and cooler. Since the 1960s, however, wheat production has moved southward and the crop is now cultivated in Gezira, White Nile, Gedarif, Kassala and Darfur States. The recent construction of the Hamadab Dam has also led to an expansion of the area for wheat cultivation. In 2008, wheat was sown on more than 300,000 ha, with an average productivity of 1.9 mt ha^{-1} (FAOSTAT, 2010).

A short success story of fertilizer use in the cultivation of wheat in Sudan

Various field research experiments, especially with wheat, have shown that multi-nutrient fertilizers are more effective than a single nutrient supply for nitrogen in increasing yields (Ali. N, *et al.*, 2002 and 2003). This is the case for both on-station and on-farm trials carried out over 1999/2000 and 2000/01 at Gezira, Rahad and New Halfa in order to test the effect of different sources and rates of N on the growth and yield of bread wheat. Both types of trials used different rates of NPK complex fertilizer, ASN and AS. Compared to the control (zero N), the application of the fertilizers resulted in a significant increase in grain yield at the three locations: 51 to 160 percent at Rahad, 39 to 162 percent at Wad Medani, and 13 to 45 percent at New Halfa.

Table 3. Yield of wheat in response to N, P and K fertilizers in four locations in the Gezira agriculture scheme (Ageeb and Abdalla, 1988).

Treatment (nutrients, kg ha^{-1})	Location / Grain yield (kg ha^{-1})				
	Dirwish	Wad Sulfab	Kab El Gidad	El Gadeed	Mean
	----------*kg ha^{-1}*----------				
N (129)	4,567	2,347	2,625	1,747	2,822
N (129)	4,741	2,287	2,968	1,468	2,866
NP (43-43)	3,146	2,839	3,249	2,547	2,958
2N;P (86-43)	4,446	3,061	3,982	2,658	3,537
2N;PK (86-43-43)	4,482	3,139	3,929	2,420	3,443
3N; 2.5P (129-64.5)	5,267	3,370	4,353	3,001	3,993
SE ($\pm$)	257	86	200	93	

Ageeb and Abdalla (1988) conducted an on-farm trial where selected treatments of N, P and K combinations were applied to wheat (cultivar Condor) at four different sites in the Gezira Scheme. Phosphorus application significantly increased wheat grain yield in all locations except Dirwish where the site is known to have fertile soil (Table 3). There was no significant response to potassium application indicating that Gezira soil had adequate amounts of available K at that time as previously reported (Finck, 1962). Wheat did not respond significantly to rates of N greater than 86 kg N ha^{-1} in the absence of P application and the response to P application increased from the Central Group (Dirwish and Wad Sulfab) to northern Gezira (Kab El Gidad). The response of wheat to P in El Gadeed Block in Managil Group was similar to that of the northern Gezira. The addition of 43 kg P expressed as P_2O_5 ha^{-1} increased wheat grain yield by 52 percent over the recommended practice (i.e. 86 kg N ha^{-1}) at Kab El Gidad and El Gadeed. The authors recommended the addition of 43 kg P_2O_5 ha^{-1} and 86 kg N ha^{-1} to wheat in the Gezira and White Nile Schemes.

3. Sorghum

In Sudan, *Sorghum bicolor* (L). (Moench) is a staple food crop for more than 75 percent of the population. It is grown all over Sudan in irrigated as well as rainfed areas. Farmers use sorghum straw as animal fodder and rarely apply fertilizers (inorganic or organic) to this crop. In 2008, sorghum was sown on more than 6.6 million ha with an average productivity of 0.5 mt ha^{-1} (FAOSTAT, 2010).

In recent years sorghum yield, even in irrigated schemes, has been declining. For this reason research with multi-nutrient fertilizer has been conducted, in which a NPK complex fertilizer, ASN and AS were compared to urea at Gezira and New Halfa (Abu-Sara *et al.*, 2002; Table 4). A yield increase was observed for the higher dose of the NPK

Table 4. Sorghum yield (kg ha^{-1}) in two locations 2000-2002 (Abu-Sara, *et al.* 2002).

Fertilizer	Dose	Gezira	New Halfa
		------*kg ha^{-1}*-----	
AS	Single	3,284	3,689
AS	Double	3,784	3,975
ASN	Single	3,380	4,260
ASN	Double	3,879	4,213
Urea; TSP	Double for N	3,444	4,022
NPK 18	Single	3,689	4,308
NPK 18	Double	4,070	4,546

Ammonium Sulfate (AS), 21% N; Ammonium Sulfate Nitrate (ASN), 26% N; and Nitrophoska NPK. (18:18:5).

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treatments in both locations, as compared to that of the standard fertilization practice using AS or urea.

4. Sugar cane

In 2008, sugar cane in Sudan was cultivated on more than 60,000 ha (FAOSTAT, 2010). All sugar estates are currently located within the central clay plain which is vertisolic with high clay content. Sugar cane, as a plant crop with successive ratoons, is known to be exhaustive to the soil. It is reported that 100 mt of cane usually removes about 100 kg N, 60 kg P_2O_5 and 150 kg K_2O from the soil (Bekker, 1999). Like other crops, sugar cane requires sufficient quantities of N, P, K, Ca, Mg and S, as well as the microelements viz.: Fe, Mn, Zn, Cu, Mo and B for its growth and development. Nitrogen in the form of urea has been the sole nutrient applied to sugar cane at Guneid for many years. However, N loss to the atmosphere as NH_3 may occur following urea application to the soil and its subsequent hydrolysis to ammonium carbonate, as reported by Tisdale and Nelson (1975).

Two experiments to evaluate the effects of other N forms were conducted by Awad *et al.* (2004) using the variety (Co6806) for two plant crops and their successive first ratoons at El Gunied sugar cane research farm over two successive seasons. The efficiency of the two fertilizer forms applied, namely ASN and Nitrophoska (NPK 18:18:5), were compared with the standard fertilization practice (4.5 N urea + 2P TSP). The results of cane and sugar yield were statistically analyzed and economically evaluated (Table 5). The results reveal that the plant crop responded well to the lower dose (2.25 N) of the two tested fertilizers, while the ratoon crop responded better to the higher dose (4.5 N) of the fertilizers. This disparity is due to the fact that the plant crop is normally preceded by a fallow, thus improving the soil residual nitrogen. Based on yield data for both tested fertilizers, the lower dose (2.25 N) is recommended for the plant crop and the higher dose (4.5 N) is recommended for the first ratoon for sugar cane production at the testing site.

Table 5. Sugar yield (kg ha^{-1}) for the two plant crops and their first ratoons (Awad, *et al.* 2004).

Fertilizer	Dose	Plant crop season I	Plant crop season II	Ratoon crop season I	Ratoon crop season II
		-----------------------------*kg ha⁻¹*-----------------------			
ASN	2.25	14,661	15,184	11,828	11,353
ASN	4.5	15,589	15,018	11,329	13,257
Urea; TSP	4.5 N; 2P	12,685	14,970	10,448	10,472
NPK	2.25 N	13,923	16,303	11,852	12,923
NPK	4.50 N	14,994	15,541	13,614	12,781
Mean		14,804	15,399	11,805	12,162
SD (+/-)		0.26	0.21	0.43	0.45

Ammonium Sulfate (AS), 21% N; Ammonium Sulfate Nitrate (ASN), 26% N; and Nitrophoska NPK. (18:18:5).

5. Vegetables

The two economic vegetables in Sudan are onion and tomato (Abu-Sara, 2001), which are produced under two production systems. The first system includes riverbank sites, the high lands of west Sudan and the sedimentary deltas in east Sudan which all provide light alluvial or volcanic soils that are characterized by moderate pH and high fertility. The second system is under the irrigated central clay plain, viz. Gezira and Rahad schemes. Vegetable yield is relatively low in these schemes as compared to the average yield across Sudan (Faki *et al.*, 1994) and similar production systems in Africa. For optimum and economic yield balanced fertilization regimes have been adopted. In 2008, vegetables were grown on more than 330,000 ha (FAOSTAT, 2010).

a) Onions

Onion is the most important economic vegetable in Sudan occupying about 33 percent of the total area under vegetables. Around 273,000 bulbs are produced each year, representing about 25 percent of the country's total vegetable production (Ahmed, 1994). Onion yield under the first type of production system is high, ranging from 14.3 to 30 tonnes ha^{-1} on the high lands of west Sudan (Abu-Sara *et al.*, 2001b) compared to the average yield in country, which is 12.4 tonnes ha^{-1}. Field experiments were carried out by Abu-Sara *et al.* (2001b) to evaluate yield response of onion to different sources and rates of nitrogen for the seasons (1999-2001) under the conditions at the experimental research farms at Rahad, Gezira and Sennar. Significant yield responses were detected between treatment means at Rahad and Gezira, while the response was insignificant at Sennar.

b) Tomatoes

Tomato is the second most important economic vegetable in Sudan occupying about 28 percent of the total area, annually producing about 294,000 tonnes, which represents around 27 percent of the country's total vegetable production (Ahmed, 1994). The effect of different sources and rates of N on the yield performance of tomato at Rahad and the Gezira research farm were evaluated (Abu-Sara *et al.*, 2001a). Highest yields were produced by treatments of 130 kg ha^{-1} N in NPK and 86 kg ha^{-1} N in ASN, as compared to the standard treatment (86 kg ha^{-1} N as urea +43 kg ha^{-1} P as TSP). At the Gezira research farm, 96 kg ha^{-1} of N in

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Photo 1. *Farmer Field Schools. Photo by Ahmed Hassan. 2002. (ARC).*

Photo 2. *Methods of fertilizer application are practiced in extension training programs. Photo by Ahmed Hassan. 2002. (ARC).*

the form of an NPK complex and AS produced the highest yields. Significant yield differences between the sources and rates of N were obtained in both seasons.

The role of education in optimizing fertilizer use

The role of education has not been evaluated specifically; however the effect of training has been evaluated from two projects.

The first was a FAO fertilizer program project (1996), which was conducted during the period of 1977-1990, to assist the Government in attaining its goals for increasing agricultural productivity, particularly among small-scale farmers. The overall immediate objective was to raise crop yields. The approach to achieving these aims was:

(a) To improve accessibility of both quantity and quality of fertilizers and related inputs to farmers at suitable places and times.

(b) To provide the farmers with information about adequate fertilizer recommendations and related improved practices.

Training was given at several levels: A high level of assistance in project management was provided to ensure sustainability in project activities at extension level and at input supply level. Field trials involving demonstrations to refine fertilizer recommendations were set up. In this work, training was given both to project supervisors and farmers. Farmers were trained in one-day sessions in the field throughout the agricultural seasons. Training was also carried out at the extension unit, in a village or at a field demonstration site. As a result of this approach, fertilizer consumption increased during the last six years of the project, especially at the small-scale farmer level. The training provided under the project represents a big achievement in general human resource development. However, this is only a start and it is clear that training must be continued, intensified, and be introduced to areas not yet reached by these project activities.

Annex: Fertilizer Recommendations for some major crops.

Crop	Recommendation ($N-P_2O_5-K_2O$, kg ha^{-1})	Location
Cotton	86-0-0	Gezira
Wheat	86-43-0	Gezira, North Sudan
Sorghum	(86-43)-0-0	Gezira, rain-fed area
Sugar cane	172-0-0	Kenana sugar estate
Rice	129-43-0	Abu Naama, Gezira
Kenaf	86-0-0	Abu Naama, Khashm El Girba
Maize	86-43-0	Irrigated Agriculture
Sunflower	(86-43)-0-0	Gezira, Rahad
Onion	86-0-0	Gezira, Rahad
Tomato	86-0-0	Gezira, Rahad

A second example was a scheme which was introduced to raise productivity by broadening farmers' choice through farming systems and water management (Ahmed and Mohamed, 2000-2002). This project was conducted during 2000-2002 and the effect of fertilizers was evaluated indirectly through the overall training. The project was carried out in the Abed Hakam area in the Gezira Scheme. Training of farmers was at the core of project activities, which included participation in training and extension through farmer field schools (FFSs). Seven Master Training Workshops (MTWs) were carried out in which the training needs in the FFSs and Rural Women Schools (RWSs) were reviewed. A training curriculum for the training of trainers (TOTs) was then developed; each MTW was followed by a TOT lasting for four days. Training to demonstrate the effect of fertilizer on crop growth is shown in Photo 1. Methods of fertilizer application either through placement or broadcasting are illustrated in Photo 2.

This project resulted in considerable progress in increasing crop productivity and cropping intensity. The intensive training program over the period of the

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project raised the awareness of the farmers to the benefits of improved cultivation practices and to the need for greater cooperation between the farmers themselves. Moreover, the combination of higher crop yield with the increases in total areas cropped contributed to the improvement of the farmers' wellbeing as a whole making them more responsive to participation.

In another training program, the farmers participated in a course on "Integrated Pest Management in Vegetables, Wheat and Cotton in Sudan 1997", which considered best production practices and chemical protocols in improving yield. The effect of this training on fertilizer use by the farmers was documented and its benefits are convincing from a comparison of those farmers who took part in the project and their neighboring farmers who did not. Both groups grew tomatoes, and although the participating farmers used lower amounts of inorganic fertilizer (urea) they obtained higher yields, with net average profits more than 100 percent greater than the neighboring farmers who received no training.

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