*Agriculture, Ecosystems and Environment*, 45 (1993) 47–58
Elsevier Science Publishers B.V., Amsterdam 

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# Irrigation development strategies in sub-Saharan Africa: a comparative study of traditional and modern irrigation systems in Bauchi State of Nigeria

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(Accepted 30 October 1992)

ABSTRACT

Baba, K.M., 1993. Irrigation development strategies in sub-Saharan Africa: a comparative study of traditional and modern irrigation systems in Bauchi State of Nigeria. *Agric. Ecosystems Environ.*, 45: 47–58.

The focus of irrigation development in most sub-Saharan African countries appears to be shifting towards small-scale irrigation based on motorised pumps. The success of this approach depends, however, on its widespread adoption by farmers who are accustomed to traditional small-scale irrigation systems based on shadoof, calabashes, buckets, etc. To get the farmers to adopt the modern system, it must be proved to be superior to the traditional methods. This study was therefore aimed at comparing the potentials of the new system with the traditional one. To achieve this, data were collected from farmers producing vegetables (tomato, pepper, onion and eggplant) under shadoof and pump irrigation systems in Bauchi State in the 1987–1988, 1988–1989 and 1989–1990 dry seasons. Analysis of the data revealed that pump irrigation is superior to shadoof in terms of resource use, yield and profit.

## INTRODUCTION

Irrigation has been defined as the application of water to the soil for the purpose of supplying moisture essential for plant growth. It is also undertaken to provide an insurance against droughts; for cooling the soil and atmosphere, thereby providing a more favourable environment for plant growth; to wash out or dilute salts in the soil; to reduce the hazard of soil piping, and to soften tillage pans (Israelsen and Hansen, 1962).

Irrigation would not be necessary if the distribution of rainfall were ideal for the growing of crops. Such perfection is, however, rarely attained and rainfall varies from one place to another and from time to time. Through a com-

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 0167-8809/93/$06.00

prehensive analysis of the rainfall patterns of Africa, Meigs (1952 (cited in Phillips (1962)) classified 36% of the total land area as under a moist climate, 22% as semi-arid, 26% as arid and the remaining 16% as desert. This suggests that for maximum utilization of land, irrigation is necessary in at least 48% of the total land area in Africa.

However, available evidence indicates that governments in sub-Saharan Africa paid little attention to the development of irrigation, until the last two decades. The recent focus on irrigation development is most likely a result of the changing demographic, climatic and ecological environments in these countries. The rapidly increasing population pressure on cultivable land makes it mandatory for cultivation to be extended to lands hitherto considered non-cultivable because of low moisture content, while the cultivated lands have to be used more intensively by multiple cropping through irrigation. Irrigation is further necessitated in this sub-region because, as pointed out by Fada and Rayar (1988), vast areas are at present witnessing devastating and unpredictable weather, characterised by prolonged periods of heat and drought, as well as progressively declining rainfall.

While the relevance of irrigation development for crop production in sub-Saharan Africa is incontrovertible, the unresolved issue is what irrigation strategy to adopt. Governments in this sub-region appear to have favoured the strategy of large-scale irrigation, as can be seen from the large-scale irrigation schemes established in Nigeria, Mali, Sudan, Burkina Fasso, Kenya, Ethiopia, etc. Reports on most of the schemes, however, indicate that the prospects of achieving the desired objective of increased agricultural production through large-scale irrigation schemes are slim. It is probably in realization of this fact that attention in these countries has, in recent times, shifted towards small-scale irrigation based on motorised pumps (Eicher and Baker, 1982).

Before government intervention in irrigation development, which led to the introduction of modern small-scale (motorised-pump) irrigation systems, farmers traditionally irrigated small plots of land using shadoof, buckets, calabashes, and blocking of streams. Variously known as shaduf, shadouf, counterpoise, dhenkali, kheteraz, and guenina, the shadoof is a simple device for lifting water using the principle of the lever. A container is suspended from one end of a long pole, with the aid of a counterweight at the opposite end of the pole and a fulcrum, water is lifted from a source such as stream, pond, or shallow well. The fulcrum, the pole, and all the supporting structures are usually made of wood, while the counterweight is made of dried mud. In the calabash system of irrigation, however, a gourd, open at one end, is attached to a rope and lowered into a stream, pond or well. The rope is then pulled manually to bring the filled gourd to the level of the farm to be irrigated. The bucket system of irrigation is similar to the calabash system except that it uses a bucket.

To successfully develop small-scale irrigation, information is needed on the potentials and constraints of a modern small-scale irrigation system, as compared with the time-tested traditional methods. The required widespread adoption of the modern system will be achieved only if it is proven superior to the traditional systems. This study is therefore aimed at comparing the potentials and constraints of motorised pump and shadoof systems, using Bauchi State as a case study.

Specifically, the study was aimed at achieving the following objectives: (1) to determine the level of resource use under shadoof and pump irrigation systems; (2) to examine crop yields under the two systems; (3) to determine the costs and returns of crop production under the systems; (4) to derive policy implications based on the results of the study.

## METHODS OF DATA COLLECTION AND ANALYSIS

This study was undertaken in three Local Government Areas (LGA) in Bauchi State, including Dass, Tafawa-Balewa, and Toro. Bauchi State is located between latitudes 9°30′ and 11°00′, and longitudes 8°45′ and 10°30′. Farming is the primary occupation of the estimated 4.8 million people in the State (Pal et al., 1991). Annual rainfall in the area ranges from 1000 to 1300 mm. The rainfall duration is approximately 5 months, usually beginning in May and ending in October, leaving a dry season of approximately 7 months. The area is, however, endowed with a network of streams (mostly tributaries of the Gongola and Bunger Rivers), along the flood plains where farmers carry out dry-season farming under a variety of irrigation systems.

From the study area, data were collected by trained enumerators twice weekly throughout the 1987–1988, 1988–1989 and 1989–1990 dry seasons using structured questionnaires. Data were collected on type, number, age and value of tools and equipment used in dry-season farming; hours of family and non-family labour input, including wages paid; type, quantity, source and cost of seed and fertilizer used each day; number and duration of water applications; quantity of crops harvested each day, quantity of harvest sold, mode and cost of transport and prices received; number of pump breakdowns, place and cost of repair, as well as expenditure on fuel and lubricants.

To obtain the data, four villages were selected from the study area, Dass in Dass LGA, Dajin in Tafawa-Balewa LGA, and Juga and Tudunwada Ribina in Toro LGA. The selection of the villages was based on the extent of dry-season farming and on accessibility. Using household lists obtained from the Bauchi State Agricultural Development Programme, 12 households using shadoof and 12 using motorised irrigation pumps were randomly selected in each of the study villages. However, six farmers (including three pump and three shadoof users) were excluded from the study for lack of cooperation, bringing the total sample size to 90 respondents.

The collected data were analysed using cross tabulations, farm budgeting (which involves calculation of costs and returns on study farms) and descriptive statistics (including arithmetic mean, range and frequency distribution). Tests of statistical significance were also conducted using ($\chi^2$) and $t$-tests.

## RESULTS

### *Level of resource use under shadoof and pump irrigation systems*

Table 1 shows the distribution of respondents according to farm size. A majority (80%) of shadoof users cultivate less than 0.5 ha, while only 40% of pump users fall into this category of land use. Farm sizes for shadoof range from 0.01 to 1.02 ha with a mean of 0.11 ha, compared with a range of 0.07 to 2.97 ha, and a mean of 0.67 ha for pump users. These results indicate that pump users cultivate far larger plots of land than shadoof users.

The distribution of the respondents according to the level of labour used is presented in Table 2 which shows that shadoof users employed a significantly higher amount of labour than pump users. In fact, up to 80% of shadoof users employed more than 2000 man-hours of labour, while only 57% of pump users fall into this category. Further analysis revealed that 38% of the total labour input of shadoof users was accounted for by water application, while only 23% of total labour input was used in watering by pump users. Labour input for watering is higher for shadoof than for pump because the shadoof is manually operated. However, pump users employed more fertilizer than shadoof users (Table 3). The volume of water applied by pump users also exceeded that of shadoof users (Table 4).

TABLE 1

Distribution of respondents according to farm size

| Farm size range (ha) | Shadoof | | Pump | |
|---|---|---|---|---|
| | Freq. count | Percentage | Freq. count | Percentage |
| ≤0.5 | 36 | 80 | 18 | 40.0 |
| 0.5–1.0 | 8 | 17.8 | 21 | 46.7 |
| ≥1.0 | 1 | 2.2 | 6 | 13.3 |
| Total | 45 | 100 | 45 | 100 |

$\chi^2 = 15.40$, D.F. = 2, significant at 1% level. Source, field survey, 1987–1990.

TABLE 2

Distribution of respondents according to level of labour use

| Labour use range (Manhours $ha^{-1}$) | Shadoof | | Pump | |
|---|---|---|---|---|
| | Freq. count | Percentage | Freq. count | Percentage |
| ≤1000 | 0 | 0.0 | 6 | 13.3 |
| 1000–2000 | 9 | 20.0 | 13 | 28.9 |
| 2000–3000 | 21 | 46.7 | 9 | 20.0 |
| ≥3000 | 15 | 33.3 | 17 | 37.8 |
| Total | 45 | 100 | 45 | 100 |

$\chi^2 = 11.65$, D.F. = 3, significant at 1% level. Source, field survey, 1987–1990.

TABLE 3

Distribution of respondents according to level of fertilizer use

| Fertilizer use range (kg $ha^{-1}$) | Shadoof | | Pump | |
|---|---|---|---|---|
| | Freq. count | Percentage | Freq. count | Percentage |
| <300 | 17 | 37.8 | 5 | 11.1 |
| 300–600 | 15 | 33.3 | 9 | 20.0 |
| 600–900 | 10 | 22.2 | 12 | 26.7 |
| >900 | 3 | 6.7 | 19 | 42.2 |
| Total | 45 | 100 | 45 | 100 |

$\chi^2 = 19.86$, D.F. = 3, significant at 1% level. Source, field survey, 1987–1990.

TABLE 4

Distribution of respondents according to level of irrigation water use

| Irrigation water use range (Ha-cm $ha^{-1}$) | Shadoof | | Pump | |
|---|---|---|---|---|
| | Freq. count | Percentage | Freq. count | Percentage |
| <10 | 11 | 24.4 | 9 | 20.0 |
| 10–20 | 34 | 75.6 | 9 | 20.0 |
| 20–30 | 0 | 0.0 | 6 | 13.3 |
| >30 | 0 | 0.0 | 21 | 46.7 |
| Total | 45 | 100 | 45 | 100 |

1 ha-cm = 100 000 L.
$\chi^2 = 41.73$, D.F. = 3, significant at 1% level. Source, field survey, 1987–1990.

TABLE 5

Crop yields under shadoof and pump irrigation systems

| Crop | Irrigation system[1] | Mean yield (kg ha$^{-1}$) | $t$-value |
|---|---|---|---|
| Tomato (*Lycopersicon lycopersicum*) | 1 | 11189.59 | 2.08** |
| | 2 | 13924.98 | |
| Pepper (*Capsicum annum*) | 1 | 8510.85 | 1.56 n.s. |
| | 2 | 9887.41 | |
| Onion (*Allium cepa*) | 1 | 7692.54 | 2.15** |
| | 2 | 10575.42 | |
| Eggplant (*Solanum melongena*) | 1 | 12809.87 | 1.34 n.s. |
| | 2 | 14821.72 | |

[1] 1, shadoof; 2, pump.
**, $t$-value significant at 5% level; n.s., $t$-value not significant.
Source, field survey, 1987–1990.

## *Crop yields under shadoof and pump*

There were slight differences in the yields of all crops over the 3 years. The yields of crops under pump irrigation, however, exceeded the yields under shadoof in each of the years.

The average annual yields of the crops produced under the two irrigation systems are presented in Table 5 which indicates that crop yields under pump systems were consistently higher than those under shadoof. The average yields of tomato, pepper, onion and eggplant for pump users exceeded that of shadoof users by 2735.39 kg ha$^{-1}$ or 24.45%, 1376.56 kg ha$^{-1}$ or 16.17%, 2882.88 kg ha$^{-1}$ or 37.48%, 2011.85% or 15.70%, respectively. These considerable increases in yield for pump over shadoof suggest that irrigation with pump is superior to irrigation with shadoof.

## *Costs and returns in crop production*

The variable and fixed costs of production are presented in Tables 6 and 7, respectively. Variable cost dominated the production cost, accounting for 95.21% of the total cost in the case of shadoof, and 90.32% for pump. A large proportion of the variable cost is attributable to labour input which accounted for 87.49% of the variable cost for shadoof, and 62.22% in the case of pump. The cost of labour input was, however, dominated by the imputed cost of unpaid family labour which accounted for 90% and 85% of labour cost, for shadoof and pump, respectively. The cost of family labour, although not directly incurred by the farmers, was imputed on the assumption that if the farmer and his family had not worked on his farm, they could have hired

TABLE 6

Average annual variable costs in crop production under shadoof and pump irrigation systems (Naira per hectare)

| Item of cost | Irrigation system[1] | Crops | | | | Total | % of total variable cost |
|---|---|---|---|---|---|---|---|
| | | Tomato | Pepper | Onion | Eggplant | | |
| Seed | 1 | 35.28 | 19.74 | 26.08 | 14.09 | 95.19 | 2.90% |
| | 2 | 30.40 | 88.13 | 42.33 | 20.64 | 181.50 | 6.78% |
| Fertilizer | 1 | 54.72 | 30.63 | 40.46 | 21.85 | 147.66 | 4.50% |
| | 2 | 35.71 | 100.04 | 48.05 | 23.43 | 207.23 | 7.73% |
| Labour | 1 | 728.02 | 1248.19 | 599.50 | 292.28 | 2867.99 | 87.49% |
| | 2 | 430.55 | 407.14 | 538.25 | 290.74 | 1666.68 | 62.22% |
| Pump repairs, fuel and lubricants | 1 | – | – | – | – | – | – |
| | 2 | 61.34 | 177.82 | 85.41 | 41.64 | 366.21 | 13.67% |
| Marketing and others | 1 | 61.96 | 34.68 | 45.81 | 24.74 | 167.19 | 5.10% |
| | 2 | 43.06 | 124.82 | 59.95 | 29.23 | 257.06 | 9.60% |
| Total | 1 | 879.98 | 1333.24 | 711.85 | 352.96 | 3278.03 | 100% |
| | 2 | 601.06 | 897.95 | 773.99 | 405.68 | 2678.68 | 100% |

[1] 1, shadoof users; 2, pump users.
Source, field survey, 1987–1990.

TABLE 7

Average annual fixed costs in crop production under shadoof and pump (Naira per hectare)

| Item of cost | Shadoof | Pump |
|---|---|---|
| Depreciation on pumps | – | 250 |
| Depreciation on washbores | – | 10 |
| Depreciation on water hoses | – | 12 |
| Depreciation on hoes, cutlasses and baskets | 15 | 15 |
| Shadoof structure | 150 | – |
| Total | 165 | 287 |

Source, field survey, 1987–1990.

out their labour to other farmers. In imputing the cost of family labour, therefore, the existing wage rates in the study area, which are based on age group and sex, were used. The variable cost for shadoof in most cases exceeded that of pump because shadoof users employed more labour than pump users. However, the fixed cost for pump was higher than that of shadoof because pump systems require higher fixed capital investment than shadoof.

Table 8 shows the gross margins for the different enterprises produced un-

TABLE 8

Average annual gross margins (gross returns less variable costs) for crop enterprises under shadoof and pump irrigation systems (Naira per hectare)

| Enterprise | Shadoof | Pump |
|---|---|---|
| Tomato | 4833.7 | 6934.84 |
| Pepper | 3099.36 | 4128.7 |
| Onion | 2317.40 | 2030.44 |
| Eggplant | 3904.00 | 6333.21 |
| Total | 14154.70 | 19427.19 |

Source, field survey, 1987–1990.

der the two irrigation systems. Gross margin is defined, in this study, as the difference between the gross returns and the variable cost of each enterprise. Gross margin was employed in this study as a measure of profitability of each of the enterprises, instead of the net farm income, to avoid the difficulty of sharing fixed costs among the enterprises. Furthermore, this technique is very useful in a study such as this, because of the low level of fixed costs, which suggests that the gross margin is very close to net farm income. As presented in Table 8, with the exception of onion, the gross margins for all the crops were higher for pump than shadoof.

## DISCUSSION

For the last two decades, many sub-Saharan African countries have pursued large-scale irrigation as a strategy for increasing agricultural production. This approach to irrigation development focuses on the establishment of dams across major rivers. The water impounded, as a result of the dams, is then used to irrigate large expanses of land, which are cleared, levelled, cultivated, and then rented out to farmers for growing crops. The establishment of such large-scale irrigation schemes has often been rationalised on the grounds that the benefits of a few large-scale schemes would 'trickle down' to the general populace. The wisdom in establishing such capital-intensive projects in capital-starved countries has, however, been questioned, and the schemes have been associated with a long list of shortcomings. For example, high levels of non-participation by local farmers has been reported for large-scale irrigation schemes in Nigeria (Etuk and Abalu, 1992; Kolawole, 1982). Also commenting on the shortcomings of large-scale schemes, Wallace (1979) noted that establishment of such schemes has forced these countries to be dependent on advanced countries who have the technology and expertise to design, construct and manage the schemes. Idachaba (1980) also observed that large-scale irrigation schemes typically involve the use of heavy equipment for levelling, which seriously disturbs the soil. He further notes, that the schemes have adverse effects on farming and fishing below the dams and often involve large-scale displacement of human settlements with potentials for social upheaval. Additional shortcomings of large-scale irrigation have been noted by Palmer-Jones (1980) and Makarfi (1987).

This study has shown fairly high returns to shadoof and small-scale pump irrigation systems. This result is corroborated by the findings of Erhabor (1982) and Ofojekwu (1982), who in separate studies reported high returns to crop production under small-scale irrigation systems. In addition, Wickramasuriya (1975) made a case for small-scale irrigation when he noted that the overall costs of production and foreign-exchange requirements are lower with small-scale irrigation than with large-scale irrigation. Furthermore, these small-scale irrigation systems are small-farmer based, and considering the fact that this category of farmer dominates the farming scene in sub-Saharan Africa, any technology directed towards them could have great potential for increasing agricultural production.

This study further reveals that irrigation with pump (which is the centrepiece of small-scale irrigation-development strategy in the study area) is superior to irrigation with shadoof (which represents the traditional small-scale irrigation system), in terms of resource use, crop yield and financial returns. Pump users cultivated larger plots of land than shadoof users. The larger farm sizes enhance the opportunity for larger output and income for pump users over shadoof users. Shadoof users irrigated smaller plots, because the shadoof system, which is manually operated and involves a lot of drudgery, has a very low discharge rate. For example, it has been reported that it requires 150 man-hours $ha^{-1}$ to apply one irrigation, using a shadoof (Nwa, 1981). This high labour requirement and low discharge rate tends to place a limit on the size of plots that could be irrigated by individual farmers, using the shadoof system. For the same reasons, plots to be irrigated with shadoof must be adjacent to the water source. The low discharge rate and high labour requirement also explain why shadoof users applied less water than pump users during the irrigation season.

Furthermore, pump users applied more fertilizer than shadoof users. The system of fertilizer distribution and sale in the study area is such that only locally powerful and properly 'connected' individuals have direct access to this substance at government-subsidised prices. Other farmers buy the fertilizer from these people at exorbitant rates. Hence, only farmers who are wealthy enough are able to purchase fertilizer in the required quantity. It could therefore be inferred that farmers who are wealthy and sophisticated enough to invest in pumps, also have sufficient funds to buy more fertilizer.

Considerable increases in crop yields for pump over shadoof were recorded. The higher yields for pump users could be attributed to the higher rates of fertilizer application by this category of farmers. Another explanation for the higher yields could be that pump farmers applied higher quantity of water which were better timed than the lower quantity applied by shadoof users.

It was found that there was a very significant (over 37%) increase in income (gross margin) of farmers using pumps over shadoof users. This could be attributed to the higher yield of crops recorded for pumps over shadoof. In addition, the pump users employed less labour, which dominated the variable costs (see Table 6), than shadoof users. This could also explain the higher income realised by pump users over shadoof users.

## POLICY IMPLICATIONS AND CONCLUSIONS

The use of pumps for irrigation has been demonstrated in this study to be superior to the use of shadoof in terms of resource use, crop yield, and financial returns. Pump also has the advantages of reducing human energy requirements and drudgery, and a higher water discharge rate. Furthermore, the land to be irrigated does not have to be adjacent to the water source as in the case of shadoof. It is believed, therefore, that a higher level of output and income would be achieved if widespread adoption of pump is encouraged. In the study area, availability of suitable land for dry-season farming does not appear to be a limiting factor. In fact, the majority of the farmers owned suitable land lying fallow during the study period. What appears to be a problem is non-availability of capital; this was listed by all shadoof users as the major constraint denying them access to pumps, which they acknowledged to be superior. To successfully develop small-scale irrigation based on pump, accessibility of small farmers to credit should be seen as an integral part of the strategy. It is believed that such credit will enable the majority of farmers to invest in pump and other improved inputs such as fertilizer and seeds, thereby increasing their output and income.

A major constraint in irrigated farming observed in the study area is the shortage of irrigation water. The majority (94.44%) of the respondents rely on naturally flowing streams and ponds for irrigation. These usually dry up later in the dry season, and farmers are compelled to dig shallow wells, which in their turn dry up, as the season progresses, usually at critical stages of crop growth probably resulting in low crop yield. To alleviate this problem, policy attention on irrigation development in sub-Saharan Africa, should focus on the establishment of small dams, more widespread than large-scale irrigation schemes. This effort should be complemented by ground-water development through the sinking of boreholes, washbores and tubewells.

Although the returns to crop production under the studied irrigation systems (especially pump) were fairly high, there appears to be room for improvement through strategies aimed at increasing crop yield. At present, yields in the study area are much lower than world average. For example, the world average yield for tomato, as reported by FAO (1990) is as high as 24 940 kg $ha^{-1}$, as against 11 189.59 and 13 924.98 kg $ha^{-1}$ recorded for shadoof and pump, respectively, in this study. The yield for pump is however, higher than the 12 345 kg $ha^{-1}$ reported for Nigeria (FAO, 1990). The relatively low yields could be attributed to irrigation-water shortages and to the lack of high-yield varieties of crops grown. In addition to ensuring adequate availability of irrigation water with minimum drudgery, provision of high-yield varieties should be properly addressed. This calls for research efforts aimed at developing high-yield crop varieties, adapted to the environmental conditions of the respective countries.

On the basis of the findings of this study, it is concluded that small-scale irrigation systems such as pump have great potential to increase agricultural production and farmers' income, if efforts are made for their widespread adoption, and if the constraints identified in this study are addressed.

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