DEVELOPMENT AND EVALUATION OF A LOW-TECH SPRINKLER IRRIGATION SYSTEM FOR SMALL SCALE FARMERS OF NORTH EASTERN NIGERIA

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Abstract- Surface irrigation by flooded basins is the dominant irrigation water distribution method practiced by the majority small scale dry season irrigation farmers along the river systems flood plains (Fadama) of the north-eastern Nigeria. This low efficient water distribution method takes greater part of the farmers' time, expenditure and labour. They do not have alternative systems that fit their farming systems, skills and economy. A simple manually operated mobile macro - sprinkler irrigation system was designed, constructed, assembled and evaluated. The study involved field requirements evaluation, design of a water distribution and carriage units, drawings, constructions, assemblage and performance evaluations. The developed system has four rotary sprinkler heads spaced 3m apart with a recorded discharge of 0.3 L/s and 0.45 L/s at maximum and minimum pressure heads respectively. The system irrigated up to 2700m^2 area of land in three strips per day. Each strip of 900m^2 was irrigated in 8 shifts and the estimated cost of one set of the system was US169. The measured system application efficiency (AE) in this study was above average, with values 75, 75 and 80%. The system distribution uniformity (DU_{LQ}) recorded across the entire irrigated field was between the range 82 -94%,. Above average values of PELQ (70.6, 71.0 and 74.0%) were recorded at the corresponding pressure(100kPa,120kPa and 140kPa) and discharge levels(309, 367 and 442lit/hr) respectively. Low PELQ range of values (59 to 67%) and (66.7 to 69.7%) were recorded. When the range of the operating pressure were low (40 to 80kPa) and when it was higher range(160-200kPa).The average CU observed in this study for the entire irrigated strip was 96.2%. There was no significant difference between means of AE when the system discharge was raised from 309, 367 and 442 litres per hour respectively(= 0.05). Also there was no significant difference between means of PELQ (= 0.05). The was also no significant difference between means of DU and CU (= 0.05).

Keywords -Sprinkler System Developed, Small Scale Irrigation, Farmer, Performance.

I. INTRODUCTION

The River flood plains (Fadama) of North-eastern Nigeria are highly fertile, productive and underlay them are shallow (5-12m deep) aquifers [8]. Bauchi State alone which is one of the six states in the North-east has about 127,000hactres of cultivable Fadama land [31].The majority of the population along the Fadama are small scale farmers with $^1/_4$ha average land holding that cultivate mainly vegetables and sometimes green maize during the dry season and rice during the wet season. Surface irrigation through flooded basins in the dry season is the commonest water distribution system in the Fadama [30]. This water distribution system has low application efficiency, uniformity and takes greater part of the farm labor energy [24],[11],[26].This constrain makes production remained subsistent to the small holder farmer in the Fadama of North-eastern Nigeria due to the high water loses and labor requirement for water lifting and distributions.

The Fadama lands of North eastern Nigeria have very high agricultural production potentials and are overlaid by shallow aquifers [8],[31] which made them very suitable for dry season irrigation farming. These potentials of the Fadama are currently being threatened by the use of flooded basins as the only option farmers adopted for irrigation water distribution. One major peril to the Fadama water resources potentials of the region is therefore lack of available options to the farmer for irrigation systems that are water application efficient, simple to operate, cost effective and adaptable to the Fadama farming environment.

II. MATERIAL AND METHODS

A. Review Stage

The envisaged sprinkler irrigation system was designed in line with the minimum technical standards in meeting the Fadama farming requirements set in this study. The new system was made up of two components; water distribution and carriage units.

The system body materials of the system were selected based on the minimum engineering standards requirement (mechanical and chemical), cost and availability of the material within the Fadama village markets.

Available steel products in the local Fadama markets were identified. Most of the Low(0.2%C with ASTM-A36) carbon steel in the market are produced in the Delta steel Company (DSC) in Nigeria and are less expensive therefore selected.

Hollow square pipes of dimensions 50mm x 50mm , 40mm x 40mm and angle bars 40mm x40mm were used as the main materials for the system frame. Push-pull handle of the system was designed such that on grip, the operator's fingers are not overlapped. The handle was made 100cm in length so that the width of an average height operator's hand is accommodated.

Hand hold height, was selected to be between elbow and hip height of an average(1.68m) height man, while the handle width was ensured to be offset from the system in order to ensure operator's foot clearance. Handle length of 1.0m was selected and made adjustable up to 1.5m length. A width of the handle was selected to be 50cm considering the human shoulder and the width of the system runway.

Springs were selected after estimating the maximum shear stress expected on the springs from the lateral hanger. The analysis of the expected stress and deflection on the two parallel springs on the two side of the lateral hanger on this system was made as described in literature[18].

A hose reel that meets the requirements of the Fadama farming system under this study was designed following hose reels design Standard M.S. 1447. The design details under the 10th schedule of the Standard include: size of the hose was selected as 50mm(nom.dia.), the side drums were low carbon steel. The dimension of the reel was 350mm wide x 1000mm drum diameter x 182mm hose- rail depth and 600mm from centre of the spindle to its fixed position (main frame). Angular-contact ball bearings were selected for the reel and the crank because they provide greater thrust capacity [29].

In the design of the water distribution unit, PVC (polyvinyl chloride) pipes and valves were decided for the new system, because PVC has minimum friction losses, pressure requirements, suitable for tropical climates[24],[11], [27])and it is locally available in the Fadama markets.

The pipe sizes commonly available in the Fadama area markets around the study area (in Bauchi, Gombe, Plateau and Kano States, Nigeria) were identified, characterized and those pipes that are cost effective and technically met the minimum standard requirements[5].

The PVC selected in this study where push-fit connectable pipes for the 50mm main line,35mm sub-main and connector fitted 25mm diameter lateral pipes. Tanjid adhesive was used as sealant to the PVC connectors (Figures 1 and 2 are the drawings of the developed sprinkler system).

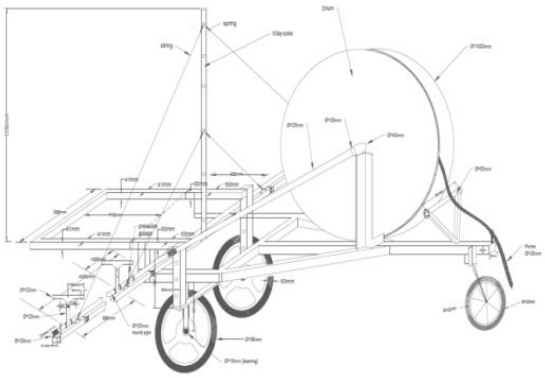


Fig 1. Isometric projection of the developed system

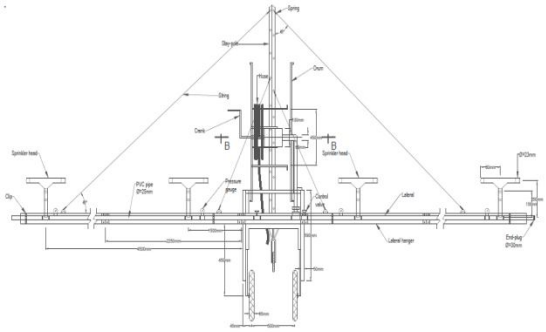


Fig 2 Rear view of the developed system

B. Operation principles of the developed system

Step 1: The irrigation field is prepared after primary tillage by constructing a number of travel paths 50cm wide across the field at an interval of 15m between one path and another . The path is for dragging the semi-hard hose of the irrigation system across the field and smooth movement of the irrigation system.

Step 2: Water under pressure from source (shallow tube-well or stream) is positioned in to a laid main supply pipe line located at one end of the farm to be irrigated using petrol pump(fig 3).

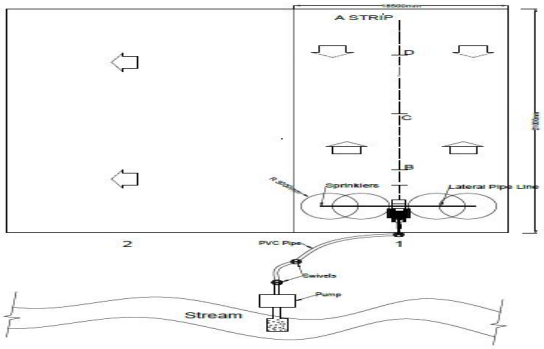


Fig 3. The sprinkler system water application shift plan

Step 3: The operator determined the irrigation time, application rate and irrigation shift. The two plans are option A (two run per strip) and B(one run per strip).

Step 4: The drag flexible hose of the system is connected to a hydrant point on the main line and the

system is positioned on the run-way with two overlapping sprinkler heads each on the two sides of the system lateral line.

Step 5: The water pump is put-on, water under pressure in the pipe lines automates the sprinkler heads which sprinkle irrigation water at a span of 6 x18m along the lateral line and a strip of 18 x 50m(900m^2) is irrigated in 8 shifts. Multiple of strips are then irrigated depending on the shape of the field.
Step 6: When the operator gets to the end of an irrigation strip, he either; (i) takes option A(return on the same path) or option B (irrigate the adjacent strip) depending on his initial plan. Twisting movements of the system from one strip to the other is facilitated by a swivel connected between the mainline and the sub-main pipe lines.
Step 7: Step 6 is repeated until the entire field is irrigated. A fadama farmer with 0.25ha would irrigate his field in three(3) strips.

C. Experimental design

The experimental design adopted for this study was a randomised block design (RBD). Overlapping sprinkler command areas were considered as blocks and the tests were repeated in three replicates. After the tests data were collected F tests to compare variability between means were carried out using SPSS software.

D. System Performance Evaluated

The depth of the applied irrigation water by the new low- tech sprinkle system was determined. The percentage of field receiving the desired amount of water or more was determined using catch cans method[22],[14] .Plates 1 and 2 are the catch can arrangement and the system wetting front at the study site. The cumulative frequency distribution of the amount of water in the catch cans (suppose to be infiltrated) at locations around the field was estimated. Then the cumulative area for each catch-can was computed and plotted against the infiltrated depth. Evaluation was carried out in early mornings when wind speed was below 2m/s with an expected minimum wind drift to the spray. Some researchers have reported a wind drift of less than 2% at 5m/s wind speed[16].



Plate 1. The manually operated mobile sprinkler irrigation system with catch cans arrangements

Catch cans in grid 0.5m apart were installed in the irrigation field across the new sprinkler irrigation system towpath (Plates 1 and 2) as recommended in literature[22]. The catch cans were selected according to the ASAE standard[4]. Distribution uniformity concept [21] was used to evaluate the water application uniformity.



Plate 2. The wetting front of the manually operated system at the study site.

Uniformity was evaluated using the Christiansen Uniformity Coefficient CU [9] as described in literature sited [22], [28]. The experiment was conducted as described in the standards guidelines[4]. Also the system application efficiencies (Application efficiency(AE) and Potential application efficiency (PELQ)) were determined using the recommended procedures[22],[14]. The data obtained was used to calculate the irrigation water application efficiency of the irrigation system as described by [1].

III. RESULTS AND DISCUSSION

The evaluated technical characteristics of the new system is presented on Table 1.

Table 1. Specifications of the Developed Irrigation System

Nozzle dia.	Pressure head (max)	Pressure head (min)	Wetted dia.	Discharge at (max.) head(l/s)	Discharge at (min.) head(l/s)	Spacing between sprinkler heads	Average coverage with three strips per day*	Average coverage at 8 shifts per strip	Cost of one set in USD
3mm	24m	12m	6-7m	0.3	0.45	3.5m	2700m^2	1350m^2	169

*maximum irrigation time per day in the Fadama is 8hours

The measured PELQ of the developed sprinkler irrigation system when subjected to nine levels (OP1 – OP9) of 20kPa incremental operating pressure from 40kPa to 200kPa is presented in Tables 2 a and b.

When the system was subjected to maximum and minimum operating pressure, PELQ values recorded were 74.0 and 57.1% respectively. The systems' highest PELQ(74.0) was when the system was subjected to 140kPa(OP4) operating pressure with a discharge of442lit/hr, while on the other hand lowers PELQ value (57.1) was recorded at the highest discharge of 570lt/hr. At the highest and lowest discharge levels in this study value of PELQ recorded (59.0% and 57.1%)were both lowest amongst the eight readings. When the performance of three types of sprinkler systems (wheel-move, conventional and centre pivot systems) were evaluated by some researchers elsewhere[9]. PELQ values they obtained were 44.0, 55.6 and 59.6% for wheel move, conventional and centre pivot systems, with distribution uniformity of 59.0% , 69.8% and 66.3% for the three systems respectively

Table 2. The Means of the Evaluated Pelq of the Developed System at Different Operating Pressure

OP (kPa)	40	60	80	100	120	140	160	180	200
Q (L/hr)	234	264	302	309	367	442	512	550	570
Mean PELQ(%)	59.0 c	67.2a b	62.5a c	70.6 a	71.7 a	74.0 a	68.4a b	69.7 ab	57.1 c

Means with the same latter are not significantly different ($p< 0.05$)

Table 2(b) ANOVA table of the measured DU_{LQ}, % at different pressure levels

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	827.454	8	103.432	6.187	.001
Within Groups	300.940	18	16.719		
Total	1128.394	26			

The measured DULQ of the new sprinkler irrigation at different irrigation events when the system was subjected to various levels of operating pressure with corresponding system discharge is presented in Tables 3 (a) and (b). Distribution uniformity (DU_{LQ}) indicates the uniformity of water infiltration within the irrigation command area [22].

In the 3 x3m sprinkler spacing the Du_{LQ} variability at varying operating pressure levels was large ranging from 51.9 to 93.5% with average of 72.8%. The values of DU were minimum, 61.9% ; maximum, 93.5% and average 72.8%. The DU at the 8 out of 9 pressure levels(OP2 to OP9) in this study were higher than the threshold(DU = 60%) established in literature[15].

DU_{LQ} was maximum (91.17, 91.37 and 93.53%) when the sprinkler system was operated at 120,140 and 160kPa with sprinkle discharge of 367, 442 and 512 lit/hr respectively.
The DU values at these three pressure levels are not significantly different($P < 0.0025$). On the other hand a DU value of 51.9% when the system was operated at 40kPa pressure and 232 lit/hr discharge was considered low because the value falls below the 60% DU threshold [15].

TABLE 3 Measured Dulq at Ten Operating Pressure Levels

OP(kPa)	40	60	80	100	120	140	160	180	200
Q(L/hr)	232	264	302	control	367	442	512	550	570
Mean DU_{lq} (%)	51.9 d	67.1 c	58.5c d	76.4b	91.2 a	91.4 a	93.5 a	61.9 c	63.8 c

Foot note - Control was the operating pressure and discharge levels that gives the 32mm/hr application rate which is just less than the study site soil intake rate(33mm/hr).

TABLE 3(B) Anova Table of the Measured Du_{lq}, % at Different Pressure Levels

Variability	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5991.832	8	748.979	33.279	.000
Within Groups	405.113	18	22.506		
Total	6396.945	26			

CONCLUSION

The manually operated mobile sprinkler irrigation system was developed to meet the farming system requirements and serve as alternative to the exiting farmer drudgery in irrigation water distribution in north eastern Nigeria.

The field evaluation of the developed system has revealed that the new system has above threshold efficiency and uniformity of water application. Therefore can be considered as one alternative irrigation water distribution system to the small scale irrigation farmers in the north eastern Nigeria.

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