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WATER RESOURCE CONSERVATION USING EMITTER-LESS DRIP IRRIGATION FOR SMALL-SCALE FARMERS

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Abstract
Water is a finite resource already stressed by the demands of today's global population, irrigated agriculture inclusive. A gravity flow, emitter-less, drip irrigation system was developed from locally available plumbing materials. The manifold lines and lateral lines were set on slopes of 1.5% and 2% respectively. Emitting holes, through which water passes directly to the soil, were drilled at 30cm interval in the lateral lines. Water was passed from an elevated tank, through a pipe filled with sand (sand- damper) before reaching the manifold and the lateral. Preliminary tests were conducted to determine design parameters, grading characteristics of the sand-damper and appropriate diameters of the drilled emitting holes. Results of the tests indicated that at an average operating head of 1.65m, an average flow rate of 1.66 liters/hr was obtained from 1.5mm diameter emitting holes drilled in the first one third length and 1mm diameter emitting holes drilled in the remaining two third lengths of each lateral lines on a layout covering an area of 11.82m^2. The system can be modified to cover different areas by varying the texture of sand-damper, the diameters of lateral & manifold pipes, emitting holes diameters and the operating head of water. The total cost of the system was ₦18, 000:00 (Eighteen thousand naira NG).
Keywords: Sand-damper, emitting hole diameter, flow rate, slope

Introduction
Limited global fresh water supplies coupled with competing demands for domestic water needs, irrigation, industrial process water and cooling water, as well as a medium of disposal of wastes has exerted undue pressure on the availability of adequate quality and quantity of water. These inadequate supplies are threatening human health, agricultural production, environmental quality and regional stability in many parts of the world. In addition, there is increasing pollution of freshwater bodies through anthropogenic activities. These competing demands have triggered a range of water crises in water quality and quantity requiring that water must be collected, used and distributed with care. It is against this background that this paper sets out to design a precision water delivery in small scale famers managed irrigated agriculture, using locally available materials. An essential element of livelihood patterns in semi-arid regions requires the effective management of soil and scarce water resources which are critical for improving crop productivity and food security. Also, as a result of geometric population growth, water for irrigation is no longer freely abundant particularly in arid zones of Nigeria. The need for water-efficient methods of irrigation has attracted a lot of research on sprinkler and drip irrigation methods. High costs of purchase, maintenance & operation (ever rising fuel prices and lack of spare parts) has made sprinkler irrigation a non-viable alternative to peasant farmer in most developing countries. Drip also called micro or trickle irrigation involves dripping water onto the soil at very low rates (2-20 l/hr) from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted. In this way it drastically reduces the irrigation water requirements without decreasing yields, and is

the last option to vegetables and tree-fruit growers in arid and semi arid regions of developing countries. However, the high investment cost and technological requirements of conventional micro/trickle irrigation is also a limiting factor in its application, especially to peasant farmers in the developing countries. Recently, the concept of Affordable Micro-irrigation systems has been identified as a commensurate drip technology for low-income farmers. These systems equally possess momentous potential for efficient agricultural water use. Considerable research has therefore been conducted in this domain with much success (Baqui and Angeles, 1995; Polak *et al.*, 1997; Bissrat *et al*., 2001; Anon., 2002; Masimba, 2003). Most low-cost micro-irrigation systems in use today such as the drum and bucket drip kits (Cornish and Brabben, 2001), and the Nica Irrigation (Anon., 2003) apply water in pulses often twice a day. Mofoke *et al.* (2004) worked on a gravity fed system that was constructed exclusively from cheap and locally available plumbing materials, incorporating a modified form of the medical infusion set as emitter. He got Distribution Uniformity for four treatments as 90.0, 91.4, 93, and 97% respectively. Umara *et al.* (2011) worked on bamboo gravity fed micro irrigation lateral system but did not use any emitter. He punched the Bamboo with holes of different diameters and evaluated the system. He obtained average discharge variations of 30%, coefficient of manufacturing variation of 9.8%, emission uniformity of 73%, Christiansen (1942) coefficient of uniformity of 92% and distribution efficiency of 88%. Awe and Ogedengbe (2010) used medi emitters on bamboo pipes in a gravity fed system. Their design involved the use of bamboo as the conveyance structure and medical infusion sets as drippers to deliver water to the field at 10, 15, 20, 25 and 30 drops of water per minutes. The variation in discharge ranged from 6.35 to 10.21 percent as the flow rate decreases from 30 to 10 drops of water per minute.

The drip emitter is the heart of a drip irrigation system. It emits water, but more importantly it regulates the water flow. An emitter could be formed by drilling a very small hole in a pipe. From this type of emitters the water tends to forcefully shoot out and more importantly, there is little uniformity of flow along the laterals. From such laterals the holes nearest to the water source will have a large water flow from them, while those at the far end will have a very small or no flow (Jess 2011, Bryan 2007). Since using a only simple hole in a pipe does not work very well, the early pioneers of drip irrigation started playing around with mechanical devices that would better regulate the flow. These devices have been given the name "emitters" (or sometimes "drippers" is used.)**.** The working principle of all emitters is water-pressure dissipation or compensation. According to Bryan (207) emitters are classified into groups based on how their design type and the method they use to regulate pressure. There are; Long-Path Emitters, which have a long water path that circles around and around a barrel shaped core, soaker hose, porous pipe, drip tape, laser tubing, which are made from materials that create porous tubing walls that the water can slowly leak out of, and short-Path Emitters which are similar to long-paths emitters but have a shorter and smaller water path and hence will work on very low-pressure systems. Other types of emitters include: tortuous-path or turbulent-flow emitters, which work by running the water through a path similar to the long path type, but the path has all kinds of sharp turns and obstacles in it, vortex emitters, which run the water through a vortex (whirlpool) to reduce the flow and pressure, diaphragm emitters, which have some type of flexible diaphragm to reduce the flow and pressure, adjustable flow emitters, which as the name indicate have adjustable flow rates, mechanical emitter, which emits water at preset interval of time from a small chamber and dripline (dripperline) which are tubings that have preinstalled emitters in them. There are 3 standard emitter flow rates, 2lit/hr, 4lit/hr and 8lit/hr (Bryan, 2007). The crop water requirement dictates which rate to choose.

All conventional drip irrigation systems require some pressure to push out the water through the emitters and some filtering mechanism to reduce clogging. This pressure has an optimum range and therefore needs some regulation. Drip systems operate quite well with a water pressure of 140 to 210KN/m^2, but water pressures higher than 280 KN/m^2 can cause ruptures in the tubing or emitters to "pop" out (Jess, 2011). Pumps from either government agencies or booster pumps are installed in drip systems to serve that purpose. However, gravity fed systems are more appropriate for low income farmers. With regards to gravity fed systems, Ella *et al.* (2009) reported that Emitter discharge increased with an increase in reservoir head height at every slope, increased slope of the mainline did not have a significant impact on average emitter discharge, no-emission of water generally occurred at the upstream laterals at mainline slopes of more than 20 percent, and emitter discharge generally decreased from the emitters close to mainline as compared to those at the end of the lateral. They also reported that; at 0 percent slope discharge uniformity increased from 0 to 3 m of reservoir height, then decreased from 3 to 5 m in height, discharge was most uniform at 0 percent slope of the laterals, higher reservoir head height results in higher uniformity of water distribution regardless of slope up to 3 m in head height.

To determine if water and chemicals are applied uniformly, it is necessary to evaluate emitter discharge uniformity and system performance. Application uniformity of drip irrigation systems can be expressed by several uniformity parameters; however, most require measurement of emitter discharge for a representative sample of the emitters in a system. Nakayama and Bucks (1986) reviewed several widely used parameters, including uniformity coefficient (UC), emitter flow variation ($Q_{var)}$, and coefficient of variation of emitter flow (CV) (Christiansen, 1942; Wu *et al*., 1979). The application of statistical uniformity for evaluating drip irrigation systems in the field using measured emitter flow rates and pressures for randomly selected emitters and manifolds was adopted as American Society of Agricultural Engineers (ASAE), Engineering Practice 458 (ASAE Standards, 1996). However, determination of these parameter values for field systems requires measurement of emitter flow rate and pressure at selected locations throughout the system. This can be accomplished in a straightforward manner for systems where the emitters are located on the soil surface; however, it is much more difficult for subsurface systems, where the emitters to be evaluated must be excavated to allow collection of water discharged. The cost of acquisition and maintenance is a serious impediment of the utilization of drip irrigation as a means of boosting food production. This research is aimed at providing a low cost means of drip irrigation using locally available materials by eliminating the use of emitters.

Materials and Methods

The research was conducted in the Agricultural Engineering Technology Premises of Samaru College of Agriculture, Division of Agricultural College Ahmadu Bello University Zaria, Nigeria. Plate 1 shows the experimental set up and Plate 2 shows its major components. Water was stored in a 140cm deep Gee-Pee tank which was elevated on 70cm block platform. The use of 70 high block platform was dictated by economics of the situation. The manifold line (made from 1" PVC pipe) and lateral lines (made from **½")** were set on slopes of 1.5% and 2% respectively. A 2.54mm (1") ball gate was connected to the main line to control the flow of water. A 2.54mm x 1.275mm (1" x **½")** reducer was fitted to tee connectors in the main line for connecting the 394 cm long 1.275mm (½") PVC pipes at 30cm interval which served as lateral lines. The laterals covered an area of 11.8 m^2. Emitting holes, through which water passes directly to the soil, were drilled at 30cm interval in the lateral lines.

Three preliminary tests were carried out to determine the best combination factors that will make the system work. In Test I, the laterals drilled with 1mm holes placed at 30cm interval were directly connected to main line after connecting a union connector with only a clothing filter. Emitter discharge was determined by measuring volume collected in catch cans and dividing it by the time taken to collect it. In Test II, the lateral lines were connected to the main line and water was passed from the elevated tank, through a 30cm long 2.54mm (1") PVC pipe filled with sand (sand-damper) before reaching the mainline. It was fetched from a building site close by, washed with water to remove the colloidal particles, and part of it was fed into the 30cm long 2.54mm (1") PVC pipe. The sand was prevented from flowing out by maintaining the clothing filter at the end the union connector. The sand was subjected to sieve analysis from which grading characteristics curve was plotted. Emitter discharge was measured at the head, middle and tail points of each lateral line. In Test III, all the conditions of the second test were maintained and in addition to that, the emitter holes at the fist one third length of each lateral (first 13 holes) were increased to 1.5mm and discharge was measured again as in the previous cases. Three readings were taken for the second and third tests and average values are presented in Tables 2 and 3.

Emitter Flow Rate Variation q_{var} was calculated using Keller and Karmeli (1974).

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \quad \ldots\ldots 1$$

Where,
q_{max} = maximum emitter flow rate,
q_{min} =minimum flow rate L/h.
Coefficient of Global Variation (CGV or CVq) was also calculated using Keller and Karmeli (1974)

$$CV = \frac{S_q X 100}{q_{avg}} \quad \ldots\ldots 2$$

Where,
Sq = standard deviation of the emitters' flow rate, L/h, q_{avg}= average flow rates, L/h.
Distribution uniformity, *DU* was calculated using (Kruse, 1978), as

$$DU = \frac{q_{25\%}}{q_{avg}} X100 \quad \ldots\ldots 3$$

Where,
$q_{25\%}$ = average of the 25% lowest value of flow rate, and q_{avg} = average flow rate.

Plate 1: Layout of the experimental plot showing single main line and ten lateral lines

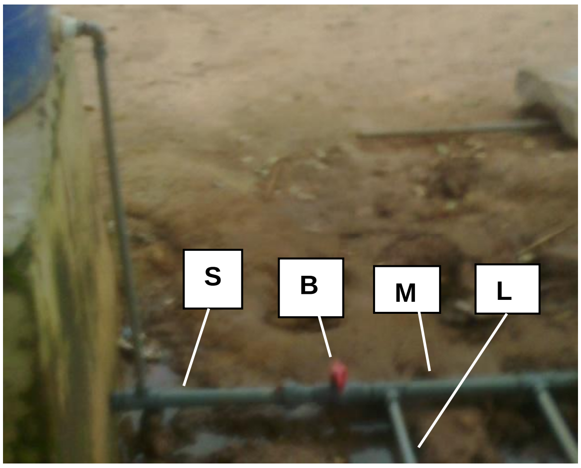

Plate 2: Components of the experimental layout
S = Sand damper, B = Ball gate, M = Manifold, L = Lateral

Results and Discussions

Results of the first test indicated that the average time it took to fill each of the first three catch cans of 165ml capacity, was only five seconds due to the high pressure from the tank. It was observed that the pressure of jetting out through the emitters gradually reduced from the head to tail of the lateral and hence it took about eight seconds to fill the last two cans. This result agrees with postulations by Bryan (2007). In the second test, water was passed through a clothing filter before reaching the mainline. It took average of 20 seconds to fill the first three catch cans and about 30second to fill the last two. This informed the decision to further reduce the pressure. Sharp sand, one of the naturally abundant materials was chosen as pressure damper. Results of the sieve analysis of the dried sample indicated that it has a uniformity coefficient (CU) of 2.5 and a coefficient of gradation (CK) of 0.54. Lesile (2000) described such soils as falling between uniform and well graded soil. Figure 1 shows the grading curves plotted from Table 1.

Table 1: Results of sieve analysis

Sieve Size (Mm)	Mass Retained	% Retained	Log of Sieve Size	% Finer
2.00	14	0.14	0.301	0.86
1.00	40	0.40	0	0.46
0.50	42	0.42	-0.301	0.04
0.25	3	0.03	-0.602	0.01
0.11	1	0.01	-0.975	-1.9E-17

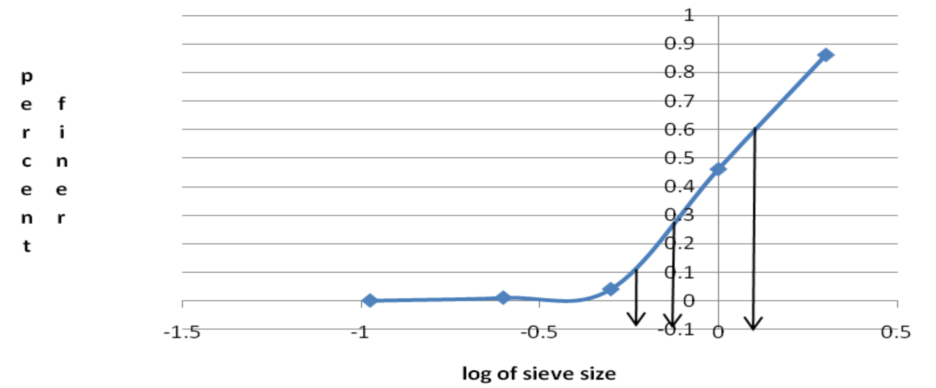

Fig. 1 : Grading characteristics curve of the sand samper

D10 =0.6mm, D30 =0.7mm, D60 = 1.5mm, CU=2.5, CK= 0.544

The use of sand-damper with 1mm holes drilled along the entire laterals yielded the results in Table 2 and Figure 2. The q_{var}, CV and DU values obtained were, 0.7, 41%, and 64% respectively. While these results do not compare favourably with international standards, where factory manufactured emitters are used they are comparable with those of Umara (2011) and Mofoke (2004) where improvised materials are used to substitute foreign ones. Most importantly, the phenomenon of the laterals or emitters closer to the water source having higher discharge is now eliminated as can be seen in the average values at head, middle and tail sections which were 1.01, 1.26 and 2.16 lit/hr respectively. The tail value 2.16lit/hr is in good conformity with international value of 2 lit/hr for gravity flow systems (Bryan, 2007). The reservoir height of 0.7 m is relatively low compared to recommended value of 3m (Ella *et al.*, 2009) which is the major reason for low average discharge of the entire system.

Table 2: Average emitter discharge in litres/hour for Test II

	Lateral lines										Average
	1	2	3	4	5	6	7	8	9	10	
Head	0.85	0.94	0.99	1.06	1.22	1.16	1.12	0.98	0.94	0.88	**1.01**
Middle	1.08	1.11	1.18	1.21	1.03	1.07	1.20	1.43	1.57	1.69	**1.26**
Tail	1.17	1.41	1.73	2.81	2.56	2.43	2.29	2.12	2.68	2.38	**2.16**
Average	**1.03**	**1.15**	**1.30**	**1.70**	**1.60**	**1.55**	**1.54**	**1.51**	**1.73**	**1.65**	**1.476**

Table 3: Average emitter discharge in litres/hour for Test III

	Lateral lines										Average
	1	2	3	4	5	6	7	8	9	10	
Head	1.25	1.23	1.67	1.00	0.95	1.64	1.77	1.93	1.98	2.88	**1.63**
Middle	1.06	1.11	1.17	1.23	1.31	1.89	1.44	1.51	1.62	1.68	**1.40**
Tail	1.35	1.32	1.54	1.39	1.72	1.82	2.21	2.68	2.89	2.50	**1.94**
Average	**1.22**	**1.22**	**1.46**	**1.21**	**1.32**	**1.79**	**1.81**	**2.04**	**2.17**	**2.35**	**1.66**

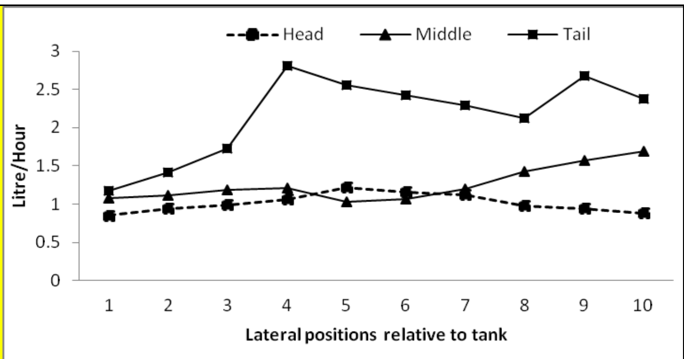

Figure 2: Discharge in litres/hr at Head, Middle and Tail of laterals for Text II

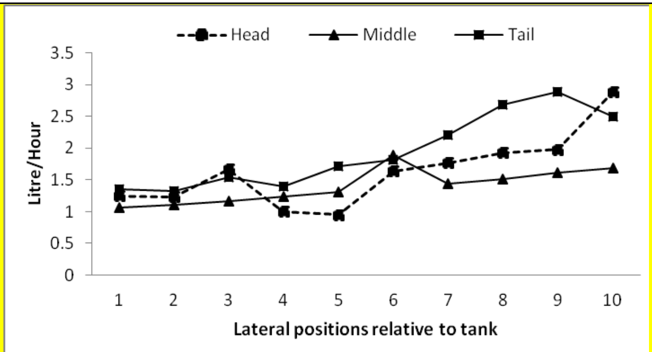

Figure 3: Discharge in litres/hr at Head, Middle and Tail of laterals for Text III

A striking observation is the fact that the tail values in all the lateral lines are higher than the values at head and middle. This has lead to the relatively high coefficients of variation. This informed the decision to increase the diameters of the emitters in the first one third length of each lateral.

The results of the Test III are presented in Table 3 and Figure 3. The q_{var}, CV and DU values are, 0.67, 32% and 76 % respectively. These values, although still not comparable with international values are better than those of the Test II. Consider the average values at head middle and tail of the laterals, 1.01, 1.26 and 2.16 lit/hr respectively. These are closer to each other than of those of Test II and hence lower value for coefficient of variation (0.67 against 0.7) and higher value of distribution uniformity (76% against 64%). The average value at the head (lead lateral) position, (1.22lit/hr) being relatively lower than the one at the tail position, (2.35lit/hr) is in conformity to findings of Ella, *et al* (2009). The overall average discharge of 1.66lit/hr is not far from the standard value of 2lit/hr (Bryan, 2007). The graph shows that the upward trend of the tail values along the laterals and along the manifold has been maintained from the results of Test II. This may be due to the slopes along these line slopes, 1.5% and 2% respectively. The best uniformity is usually achieved at 0% slope of the lateral lines (Ella, *et al*, 2009).This is not the ultimate aim but it is a positive change from the expected low or no discharge at all which would have been obtained in the absence of the sand damper. The results are still preliminary but are indicative of positive trends towards internationally accepted values from systems with factory manufactured emitters.

Conclusion

A simple drip irrigation system has been developed from locally available materials. Emitter, the major principal component of conventional drip irrigation systems was not used in this system. It is function of moderating the flow by passing the water through long paths has been replaced with a sand-damper placed at entry point to the manifold lines. The flow variation has been further diminished by increasing the emitting hole diameter at the head ends of one third length of the lateral lines The system has an overall average discharge of 1.66lit/hr and distribution uniformity of 68% and could be used by peasant farmer in developing countries because it is cheap, costing only ₦18,000.00 (Eighteen thousand naira NG) for an area of 11.82m^2 and it does not require very special skill to install or manage.

Recommendation

Further research should be done on the slope of the lateral and manifold lines as well as, length/ texture of the sand-damper and the emitting hole diameters at the middle and head of the laterals. The reservoir height should be increased and possibility of increasing the number of sand damper along the manifold line should be explored when the size of the layout is larger.

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