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Bucket-Drip Fertigation Effects on Vegetable (Cucumber) Grown on Tropical Acid Sands

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Abstract: High infiltration rate, leaching and erosion woes sustainable vegetable production on acid sands of southern Nigeria. To combat the problem, Bucket-Drip Fertigation (BDF) technology was tested for two dry seasons (no rainfall). Cucumber (*Cucumis sativus*) was sown as test crop. The soil was analyzed before and after each experiment. The treatments were: source of water (drip or hand watering or 0); source of nutrients (fertigation or dry broadcast or 0) and surface cover (with or without plastic mulch). The treatments were replicated three times and laid out using Randomized Complete Blocks (RCB) design. The soil infiltration rate exceeded 25 cm h^{-1} suggesting sprinkler or drip system as appropriate. Volume of irrigation water supplied every second day was 0.05 m^3 uniformly per 15 m^2 bed. Results showed that BDF and plastic mulch proved superior to other tested sources water and nutrient applications. On first trial, BDF significantly ($p<0.01$) increased the fruits yield of edible cucumber from 0.77-2.30 Mg ha^{-1}. In the second experiment, BDF+WPM, BDF+BS and BS+NPK increased cucumber yield by 125, 10 and 17%, respectively. Thus, drip fertigation with bucket kit could be particularly useful for small scale vegetable production during dry seasons in southern Nigeria.

Key words: Bucket-drip kit, fertigation, soil nutrient management, acid sands, season, southern Nigeria

INTRODUCTION

Conventional drip irrigation systems are uncommon and expensive for small scale farmers as such, adapting such systems for local use in developing economy is imperative. The modified system is capable of saving time, maximizing resource efficiency and providing more income to the poor majority in peri-urban and rural areas that practice market gardening. Drip fertigation is a modern agro-technique of injection of nutrients into irrigation water and application through the drip irrigation system. The drip irrigation kit developed by International Water Management Institute (IWMI) includes a bucket to hold water, a filter and rubber or plastic tubing with small holes for supplying water to the plants (International Water Management Institute, 2003). Department for International Development (2004) referred to this bucket-kit or drum-kit for drip irrigation as Affordable Micro-Irrigation Technology (AMIT). This AMIT has been fully described as an attempt to use modern technology to meet the basic needs of millions of people. That basic need is food (Chapin *et al*., 2002; Department for International Development, 2004). The kits are easy to install and the systems are expandable: so the farmers can start small and scale up as their financial situation improves. The combined use of AMIT and drip fertigation is what this paper refers to as Bucket Drip Fertigation (BDF). Drip fertigation is known to increase crop yield and maximize economic returns per unit land area (Storlie *et al*., 1995). Plastic mulch has been known to effectively conserve soil water thereby reducing water stress, cleaner vegetables and suppress weed (Sanders, 2006). Alcanter *et al*. (1999) reported that fertigated tomatoes yielded more had higher dry matter and improved quality parameters compared to conventionally irrigated and fertilized crops.

Fertigation has been found superior to other methods of fertilizer placement for trickle irrigated crops and produces higher crop yields, with substantial savings (of up to 50%) in fertilizer usage. Some additional advantages of fertigation in modern agriculture are described in the literature (Asadi *et al*., 2002; Hou *et al*., 2007; Hagin *et al*., 2002). This study was conceived to determine better ways of supplying nutrients and conserving soil water for growing vegetables during dry seasons in the wet-humid tropics. For the peculiar sandy, porous, easily leached and eroded soil problems, coupled

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with fairly high level of poverty in the region, the affordable bucket drip fertigation system could be the solution for small-scale farmers.

Objectives: The objectives of this research project were:

- Test the fabricated bucket-drip fertigation kit on the yield of vegetable (*Cucumis sativus*) and soil fertility indicators
- Investigate the combined effect of sources of nutrient, sources of water and soil cover on the yield of crop and on the soil
- Establish the need for further investigation of efficient ways of supplying nutrients and water required for vegetables production during dry seasons in porous and highly leached soils of southern Nigeria

MATERIALS AND METHODS

The study area: Two field studies were conducted at Teaching and Research Farm, Faculty of Agriculture, University of Calabar, Nigeria [Lat 04°56' N; Long 008° 21'E]. Mean annual temperature range 25-33°C; mean annual rainfall range for 20 years is 2725-3500 mm. The rainy season occurs between April and November, while dry season starts in November and lasts through March. The fertigation experiments were conducted between October and January to have crop growing into the dry seasons in order to measure the impact of irrigation on the porous sandy soil of the area.

The test crop: It was Cucumber (*Cucumis sativus* L.). Detailed botanical and agronomic information about cucumber such as environmental constraints, water and fertilizer requirements have been documented by MacDonald and Low (1984) and Grubben *et al.* (2004). The seeds were sown directly at 60×90 cm.

Soil of the study area: The soil has been classified as Typic Paleudults in the USDA Taxonomy (Esu, 2005) and Ferralitic soils (Ferralsols) in the FAO/UNESCO classification (Enwezor *et al*., 1989). The soil is commonly called Acid Sands of Southern Nigeria and since they occur mainly in the high rainfall areas it is not only highly leached because of high infiltration rates but also subjected to water erosion (Udo and Sobulo, 1981). Because of the dominance of sesquioxides and low clay and organic matter content, the soils are sandy and generally acidic.

Soil sampling and laboratory analyses: Composite soil samples were collected at depths of 0-15 and 16-30 cm analysed for physicochemical properties before and after each of the experiments. The samples were bulked into a Zcomposite for the laboratory analyses. Cylindrical core measuring 5.8 cm high and 5.5 cm wide was used to take samples for bulk density determinations (Blake and Hartge, 1986). Soil samples were air-dried, ground and passed through 2.0 and 0.210 mm sieves and the physicochemical properties were determined using routine methods described by International Institute of Tropical Agriculture (1979). However for soil reaction, a ratio of 1:2 (soil:water) was maintained and the pH read with a glass electrode. Organic Carbon (OC) was determined by the Walkley and Black wet-oxidation method described by Nelson and Sommers (1996) and Soil Organic Matter (SOM) was estimated by the Van Bemmelen factor of OC×1.724 = SOM, though it might be an under-estimation for this mineral soil (Nelson and Sommers, 1996). Total porosity was calculated from bulk density and particle density data using the formula in Eq. 1:

$$T_p = \left(1 - \frac{\rho_b}{\rho_p}\right) \times 100 \quad (1)$$

Where:
T_p = Total porosity (%)
ρ_b = Bulk density
ρ_p = Particle density

Particle density was assumed to be 2.65 Mg m^{-3} as given by Danielson and Sutherland (1986) for many mineral soils.

Infiltration rate determination: To determine the correct mode of irrigation delivery, infiltration rates was carried out. Double rings infiltrometer, locally fabricated with steel to standard specifications (ELE International, 2003) was used to carry out infiltration rate determination. The outer and inner rings were 55 and 33 cm in diameter, respectively. Both rings were 30 cm high. The rings were driven concurrently into the pre-wetted soil, approximately to 12 cm depth, before running the infiltration for 210 min and the rate was calculated

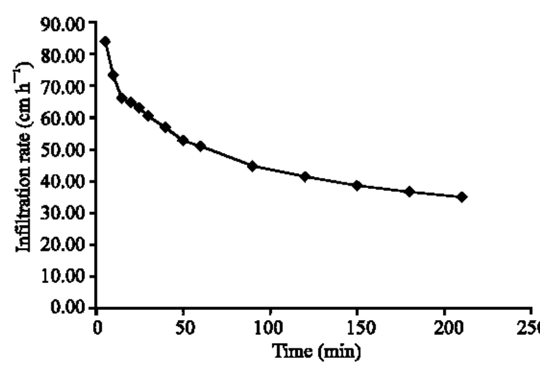

Fig. 1: Mean infiltration rate of the field used for the modified drip fertigation exoeriments

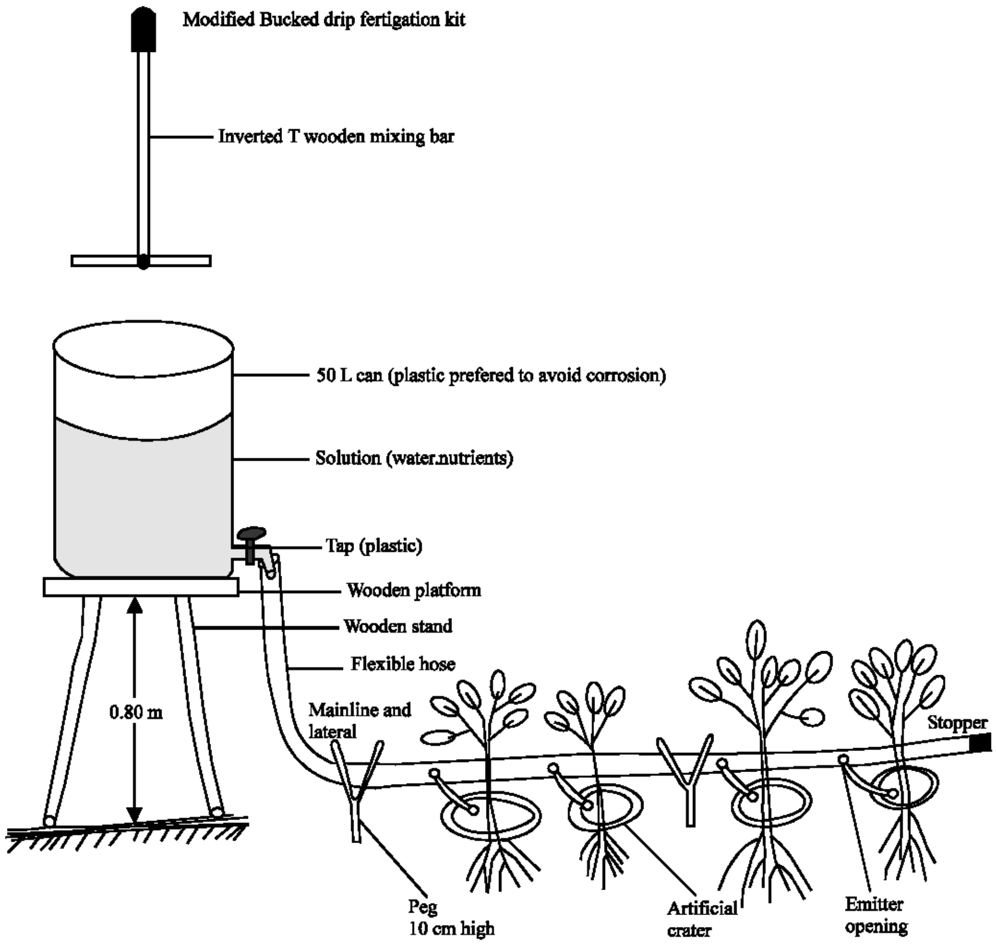

Fig. 2: The modified bucket-drip fertigation kit structure (Designed by Pout B. Okon, Department of soil sceience, UNICAL colobor)

following the procedure described by Landon (1991). The Infiltration Rate (IR) of the soil as shown in Fig. 1, indicated that the soil has very high IR (>25 cm h^{-1}). In this case, according to Landon (1991), the recommended irrigation system is the sprinkler or trickle/drip irrigation system.

The Bucket Drip Fertigation (BDF) technology and procedure: The bucket-kit drip irrigation system developed by Chapin *et al.* (2002) and International Water Management Institute (2003) was fabricated locally and used in these experiments. The bucket drip fertigation kit comprised of bucket with tap and hose. The tap controls the flow of the nutrients solution and perforations on the hose were at exactly the plant spacings. The kit was sustained on a wooden platform 80 cm above ground (Fig. 2). The hose served as lateral while the perforated holes function as emitters. Flow uniformity was difficult due to the flexibility of the hose but manual control by the use of Y-pegs ensured uniform flow of nutrient-laden water to the plants.

Experimental design and treatment materials: Randomized Complete Block (RCB) design was used. Each treatment was replicated three times in the 1st year and four times in the 2nd year. Raised beds were used for the treatments. Each bed measured 1.5×10 m, giving 15 m^2 with 0.5 m border for all the experiments. An equal volume of water was applied to all treatments except control. About 50 L (0.05 m^3) of water was used in mixing the fertilizer and applied per bed every second day until fruiting. The University pipe-borne water was used though the quality was not tested, the water was drinkable (Fig. 3).

Compound fertilizer; NPK 12-12-17 was used. After calculations, 1.25 kg fertilizer was applied per bed (15 m^2). The actual application rates were 100 kg N, 100 kg P and 142 kg K ha^{-1}. The dosage was uniformly divided and split applied at intervals for 4 times.

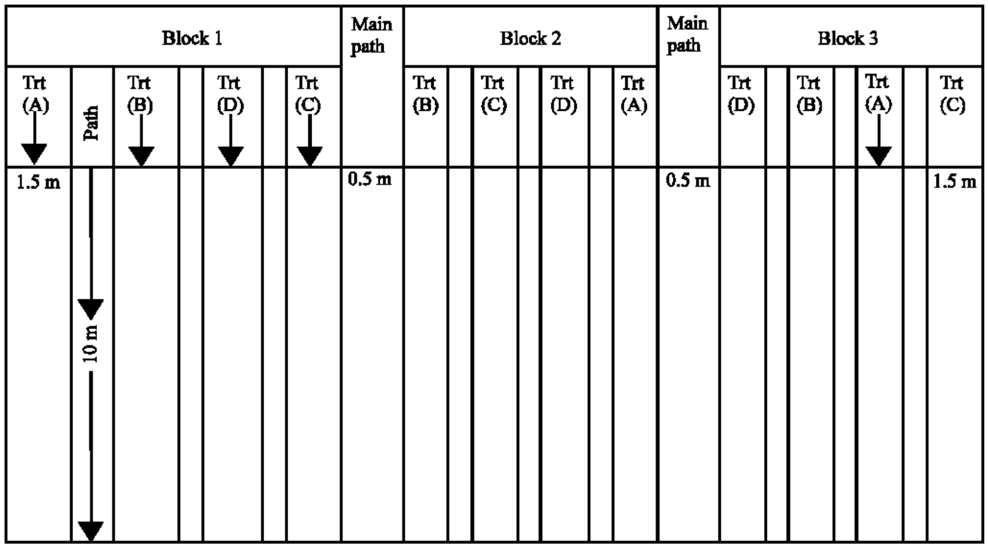

Fig. 3: Experimental layout of the field plots (on raised beds). Arrows indicate direction of water flow through the bucket drip laterals. Flow uniformity was achieved manually using both Y-pegs and inverted Y-pegs. Though, not drawn to scale here, the beds were uniform in area (15 m^2) and measured exactly 1.5×10 m. The treatments were completely randomised in each block

Table 1: Treatment combinations experimented upon

Treatments	Source of water			Source of nutrients			Soil cover	
Sub-treatments	Hand-watering*	Bucket-drip	None	Dry-broadcast*	Fertigation	Control (None)	Without mulch* (Bare)	With plastic mulch
1st year (2004)	A	A	A	A	A	A	A	NA
2nd year (2005)	A	A	NA	A	A	A	A	A
3rd Year (2006)	A	A	NA	A	A	A	A	A

*Commonly practiced in the study area; A = Applied; NA = Not Applied

Treatments: Table 1 shows the treatments that were replicated thrice and applied randomly to 12 beds. In 2006, 20 tons ha^{-1} of poultry droppings (manure) was uniformly spread and worked into the plots followed by the NPK 12-12-17 fertilizer.

Statistical analyses: Descriptive statistics were computed on all soil and crop variables after each experiment using GenStat 7.2 DE (GenStat, 2007) software. Analyses Of Variance (ANOVA) and mean separations using Least Significant Difference (LSD) were carried out.

RESULTS AND DISCUSSION

The soil: Both the initial inherent and post harvest physicochemical properties of the soil are shown in Table 2. Most of the soil properties indicated moderate to extremely low limitations when evaluated against the critical limitation classifications of Landon (1991) and Lal (1994). The texture of the soil was sandy loam to loamy sand which was moderately limiting crop growth while Available Water Capacity (AWC), generally <2 cm cm^{-1}, showed extreme moisture limitation. Infiltration rate was very rapid, generally >25 cm h^{-1} (Fig. 1); hence, overhead irrigation or drip/trickle methods of irrigation are most appropriate (Landon, 1991). The gravimetric soil water values were <20% which cannot maximally support sustainable crop production. This also revealed the need for total irrigation during dry seasons judging from the porous characteristics of the soil. The soil had no problem of salinity. The measured electrical conductivity was below 0.1 dS m^{-1} this was below critical levels that could negatively affect crop production.

In terms of fertility, the soil was very poor. By the standards of Enwezor *et al.* (1989) and Lal (1994), Total Nitrogen (TN), exchangeable K and Organic Matter (OM) were rated low that is their values were below the critical level that can elicit optimum plant response. The soil pH range of 4.6-5.5 severely limits the response of the test crop and availability of nutrients as some nutrients could be immobilized. Organic Carbon (OC) was often surprisingly low at the start of experiments and advanced from 8.0 g kg^{-1} in the first experiment to 17.0 g kg^{-1} in the

Table 2: Pre-planting and post-harvest soil analyses of the study area

		Year 2004		Year 2006	
Soil parameter (determined)	Unit	Preplanting	Post harvest	Preplanting	Post harvest
Sand	g kg^{-1}	666.000	700.000	768.000	868.000
Silt	g kg^{-1}	244.000	167.000	76.000	77.000
Clay	g kg^{-1}	90.000	133.000	156.000	55.000
Texture		SL	SL	SL	LS
Bulk density	g cm^{-3}	1.170	ND	1.460	ND
Total porosity	%	55.850	ND	44.910	ND
Reaction (pH)		5.040	5.400	5.300	5.500
Initial water content	% vol (w/w)	19.470	ND	17.490	ND
Organic carbon	g kg^{-1}	8.000	14.100	1.220	17.000
Organic matter	g kg^{-1}	13.790	24.400	2.110	29.400
Total nitrogen	g kg^{-1}	0.700	0.060	0.050	0.070
Available phosphorus	mg kg^{-1}	42.900	22.000	18.000	12.000
Exchangeable Ca^{++}	cmol kg^{-1}	1.600	2.000	2.110	2.010
Exchangeable Mg^{++}	cmol kg^{-1}	1.000	0.600	0.700	0.700
Exchangeable K^{+}	cmol kg^{-1}	0.100	0.100	0.050	0.050
Exchangeable Na^{+}	cmol kg^{-1}	0.060	0.030	0.040	0.030
Exchangeable acidity	cmol kg^{-1}	1.560	2.080	2.880	2.560
Effective CEC	cmol kg^{-1}	4.320	4.810	5.780	5.350
Base saturation	%	64.000	56.700	50.170	52.100
Electrical conductivity	dS m^{-1}	0.025	0.031	0.047	0.060
Infiltration rate	cm h^{-1}	25.600	ND	26.400	ND

ND = Not Determined, LS = Loamy Sand, SL = Sandy Loam

second trial. This was peculiar to the acid sands when cultivated as rapid mineralization takes place. But in this case, the rapid increase could be attributed to addition of organic manure (poultry droppings) during the second cultivation. This observation lends added weight to the study. It clearly shows that addition of organic materials such as poultry droppings, pig dung, composted sewage and farm yard manure could help restore rapidly declining OM in acid sand soils of southern Nigeria. However, available Phosphorus (P) was the only variable that met the minimum crop response limit. The acid sand soils of southern Nigeria have been noted for this inherently high P status, >20 mg kg^{-1} (Udo and Sobulo, 1981) and this has remained unchanged. In the post-harvest soil analysis, P ranged from 11.66 to 90.00 mg kg^{-1} showing self-sufficiency.

Crop yields: In 2004, cucumbers were harvested and weighed as they reached consumption (edible) stage that is 15-20 cm long and the fresh fruit yield recorded against each treatment. The highest yield was obtained from the bucket drip fertigation plots (Table 3). Fruiting started 48 days After Planting (DAP) in plots with BDF while plots with dry broadcast fertilization plus hand watering started yielding at 55 DAP. In the control, no fruit yield was recorded as the plants did not survive the scorching heat and unfavourable dry soil conditions. The death of the crop in the control plots underscores the need for irrigation and was clear evidence that without irrigation vegetables cannot survive the short (about 3-4 months) dry season even in this high rainfall ecological zone. In Table 3 there were high significant (p<0.001) differences

Table 3: Yield (Mg ha^{-1}) of fresh edible fruits of cucumber as affected by different methods of irrigation and nutrient application in 2006

Treatments	Block 1	Block II	Block III	Block IV	Mean (Mg ha^{-1})
BDF+WPM	2.10	2.68	3.17	3.17	2.92^{a}
BDF+BS	1.23	1.47	1.98	1.06	1.43^{b}
BS+NPK	1.73	1.07	1.13	2.18	1.52^{b}
BS (control)	1.60	1.18	1.36	1.04	1.29^{b}
Mean	1.67	1.58	2.04	1.86	1.79

$LSD_{0.05}$ = 0.83; S.E. = 0.261; CV% = 29.1 Means followed by the same letter(s) are not significantly different at 5% level of probability

amongst the treatments; BDF was significantly different from either hand watering or dry broadcast of fertilizer. This result gave a sense of direction for subsequent year's experiments. Further conservative measures were introduced and the less significant measures left out. There was no block effects (p = 1.94 for blocks). Fertigation with the adapted bucket-drip irrigation kit was superior to hand watering.

In 2006, the growth and yield of cucumber was determined by measuring the number of fruits per plant and weight of edible fruits of cucumber. The number of fruits per plant harvested 67-80 DAP was significantly higher in WPM+BDF plots than other treatments. A mean of 10 fruits were harvested in plots treated with WPM+ BDF. The yield of fresh edible fruits of cucumber was significantly higher in WPM+BDF plots than others. A mean yield of 2.92 Mg ha^{-1} was obtained. Though this yield was significantly higher than the control and other treatments it was lower than what is reported in the literature. A yield of 30 Mg ha^{-1} has been recorded under ideal conditions (IFA, 1992). This low yield could be attributed to the poor soil conditions, time and duration of cultivation.

The number of fruits harvested between 67 and 80 DAP from white plastic mulch plus drip fertigation treatment were significantly higher than those obtained from other treatment at $p<0.05$. Moreover it need be stated that there was no pesticide use during any of the experiments and diseased conditions were not documented.

In the 1st year, Bucket-Drip Fertigation (BDF) significantly ($p<0.001$) increased the fresh fruits yield of cucumber from 0.773-2.28 Mg ha^{-1} in plots treated with NPK dry broadcast combined with hand watering compared to BDF, respectively. In the 2nd year, significant yields were recorded for cucumber fresh fruits (weight and number per plant) under drip fertigation with the bucket-drip kit. Plots treated with WPM+BDF yielded significantly ($p<0.01$) 2.92 Mg ha^{-1} edible fresh fruits against 1.29 Mg ha^{-1} in the control. Furthermore, double the numbers of fresh edible fruits were obtained in the plots treated with WPM+BDF compared to control (bare soil with hand watering).

CONCLUSION

Significant issues in these experiments were fighting against poor soil conditions during dry season and testing alternative methods of fertilizer and water application for the poor small scale farmers. Vegetable crops do not survive through dry seasons even in high rainforest ecosystem of southern Nigeria except under irrigation. All experiments were under natural field conditions as such the small scale farmers can be assured that attempts in adapting what is reported here could bring similar or better results. Overall, the bucket-drip fertigation system was locally fabricated and tested and found to be superior to the common practice in the study area that was used as control. The effects of using the bucket drip kit in application of fertilizer and irrigation water were always positive and brought about significant increments in the yields (weight and number) of edible cucumber fruits. This study revealed that with bucket-drip fertigation, split application of fertilizers in several small quantities can be simpler and more efficient task, especially in the porous acid sand soil of the southern Nigeria.

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