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Development of nano irrigation system with clay diaphragm for reduced water loss in vegetable production in low income countries

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Abstract Water resources will be more affected as the effects of climate change continues to manifest in the environment. Since agriculture in the poor countries of the world still remain largely rainfed, the effect of climate change will leave greater impact on agriculture in those countries. Any effort made to improve water use efficiency in agriculture is worthwhile. This paper presents a report of the development of nano-irrigation system using molded clay for emitter diaphragm. The clay material was sourced locally from the deposit around the pottery community in Isan-Ekiti, Nigeria. Varying quantities of sawdust was mixed with clay before molding. As a result, seven different treatments of clay: sawdust ratios were made viz; 100:0, 90:10, 80:20, 70:30, 60:40, 50:50 and 40:60. The mold samples were sundried and later fired in the kiln at 700 º C. This process helped to strengthen the molds and eliminate the sawdust burnouts. From the water discharge test conducted by connecting the emitter to the discharge end of a water-hose the 80:20 treatment showed a discharge of 8.6 x 10^{-6} l/s (approximately 1 liter/day). The corresponding discharges from 70:30, 60:40, 50:50 and 40:60 were 4.3 x 10^{-5} l/s (2 liter/day), 1.6 x 10^{-5} l/s (approximately 4 liter/day), 1.4 x 10^{-5} l/s (approximately 5 liter/day) and 1.2 x10^{-5} l/s (approximately 7 liter/day). Compared to the commercial drippers manufacture by Netafim Ltd the discharge was far more efficient in curtailing irrigation water loss. The 70:30 sample was found more suitable for meeting the discharge of water quantity equivalent of the water requirement of pumpkin and okra vegetables. This was confirmed in the field experiment conducted with the crop in question. On the material utilization platform, the developed emitter is 100 times cost effective when compared to cooking pot and the economic return to the rural women far outweighs that of other pottery wares.

Key-words: irrigation system, water loss, low income countries, climate change.

1. Introduction

Irrigation, according to Michael (2000) and Michael and Odjah, (2003) is the artificial application of water to farmland and the crops in order to boost agricultural production and performance. It is also used for maintenance of landscapes, support re-generation of plant cover on dry lands and a means to supplement inadequate supply of rainfall mostly under rain-fed agriculture (Williams and Robert, 2007). The need to manage water in a most economic and sustainable, yet environment friendly manner, have been s driving force propelling experts concerned with irrigation and environmental protection to evolve more efficient and effective irrigation over the years.

In the recent time, record of irrigation development time-line shows that the practice had moved distantly from the flooding, basin and furrow irrigation types to a more water-economical systems, like drip irrigation (Oladipo and Adewumi, 2013). Further advancement not only in the field of irrigation technology, but also in other areas of agricultural science which had opened awareness to more evolution of water saving irrigation systems. Today, crop yield is preferably measured in ‘yield per drop (of water) as against the earlier dimension of ‘yield per hectare’ (Smajstria and Zazueta, 2002; Smith, *et al.*, 2010).

The need to accelerate the world agriculture towards climate change adaptation gives path of irrigation advancement a new direction. According to Van-Lieshout and De-Brower, (2008) arid and semi-arid regions of the world will experience more dryness in event of global temperature rise by 2ºC (IPCC, 2001; World Bank, 2010; World Water Week, 2011 and Brouwer *et al.*, 2010). To enhance the adaptation capacity of the economy of those areas likely to be worst hit by climate change effects have been, and still being suggested and implemented (Parry, 2007). Such included in the agreements of Rio, Geneva, Mexico, Copenhagen, climate change conventions.

Despite all those Holzapfel *et al.*, (2010) still expressed the fair that most poor countries particularly located in the vulnerable dry regions will experience a more adverse condition, such as prolonged dryness, reduced soil moisture conditions, poor crop yield, crop failure, food insecurity, hunger and starvation, locally displaced people and migration. To further strengthen the adaptive capacity of the so called vulnerable people and irrigated agriculture amidst increasing evapotranspiration rate, more water efficient systems reported by Oladipo *et al.*, (2013), Oladipo and Adewumi, (2012), Ismeal *et al.*, (2001) were developed.

Nano technology was considered a useful technology for agriculture in the recent time (Baruli and Dutta, 2009) and in water management and crop production (Schroeder *et al.*, 2005). EFSA, (2009). FAO, (2010) and Nair, *et al.*, (2010|) viewed the promise of Nanotechnology in crop breeding, production and plant-protection methods. While Khodakovskaya *et al.*, (2009), Zhing *et al.*, (2005) and Lin and Xing, (2007) reported the application of Nano technology in seed germination rate enhancement for tomato, spinach and rice.

Hillie and Hilophe (2007) reported that a number of Nanotechnology devices and systems will be of benefit to farmers in the world especially those in the developing countries among them are; for purification of irrigation water, nano-enabled water treatment membranes filters from carbon nanotunes, nanoporous ceramics and magnetic nanoparticles. Nanotechnology had been used to apply fertilizer to crops with very little or no left-over leakage that may pollute groundwater and the environment (Maysinger, 2007, Bhalla and Mukhopadhyay, 2010).

Tuteja and Gill (2013) and Fang *et al.*, (2004) reported that crop growth could be enhance if irrigation water treated with nanotechnology devices like nano-863 is applied to it. As good and promising as Nanotechnology appears to be, the level of advancement and cost of achieving the end product still reside in the custody of the advanced countries like USA, Germany, Japan and France. However, China is rapidly developing in this realm of technology and the discovery and publications from Chinese experts are favorably competing at the International scene. For other developing countries to have a fair share of the nanotechnology race, attention necessarily have to be shifted to materials with potential structural make-up for nanotechnology yet available and affordable. Clay happens to be among such materials. Clay properties include; plasticity, shrinkage, fineness of grains, cohesion etc. The essential nano-clay is montmorillonite (Torney and Trewyn, 2007). For its unique properties and structure, clay was isolated for producing device s that could be deployed for nanotechnology application especially in water filtration and disinfection. This technology had been used to provide water to crop but the level of sophistication was very low. This is why this work was facilitated and implemented.

2. Materials and Methods

The study was undertaken in the premise of the Federal Polytechnic Ado Ekiti Nigeria (Long. 18ºE, Lat. 5ºN). The clay emitters were molded using locally fabricated hydraulic press and the field evaluation was done in a greenhouse within the same premises. In order to increase the porosity of the emitter, different proportions of sawdust was incorporated into the clay past before pressing. Six samples of different porosities were produced while one comprising of puly clay was equally made and used as control sample. Each sample was thoroughly mixed to paste out of which 0.5 kg was poured into the mold and left to solidify. The emitters were there after air-dried and fired in the kiln for 12 hours at 700 ºC. This treatment allowed the emitters to become stable while all the burn-outs were completely eliminated (Figure 1).

	
Plate 1: Burnt clay-emitter of clay: burnout ratio of 80:20	Plate 2: Burnt clay-emitter of clay: burnout ratio of 70:30

Figure 1: Burnt clay-emitter of clay. Plates 1 and 2.
Source: Elaborated by the authors.

Each of the selected emitter was covered up to eliminate leakage and thereafter connected to water source with a tube. The emitter was gradually filled up under gravitational flow and left to soak. The net weight of the emitter gave the amount of water held within the body of the emitter before releasing it to the soil. The electron microscope view of the structure of the sample is shown in plates 3 and 4. The open pore concentration in clay area of $1.6x10^7$ $(\mu m)^2$ was 11 for clay sample (B) while that of sample (C) has 5 pores for a similar sample area (Figure 2).

SN	Clay-Emitter Sample	Burn-out Content (kg)	Clay Content (%)
1	A	0	100
2	B	0.1	90
3	C	0.2	80
4	D	0.3	70
5	E	0.4	60
6	F	0.5	50
7	G	0.6	40

Chart 1: Sample of emitter and the sawdust burnout content.
Source: Elaborated by the authors.

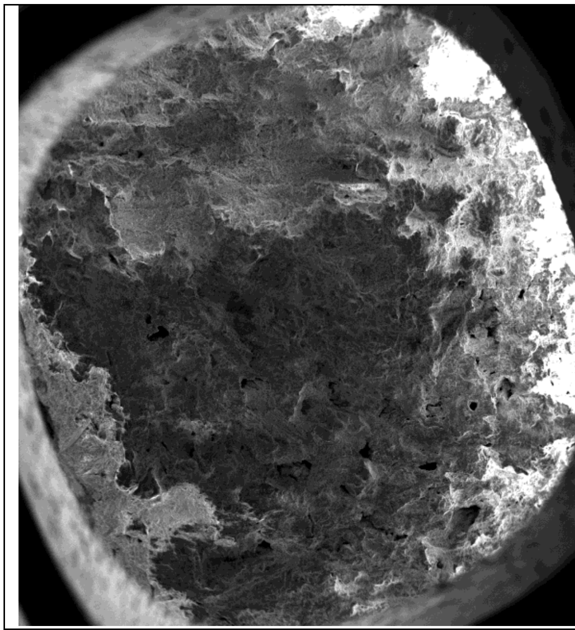	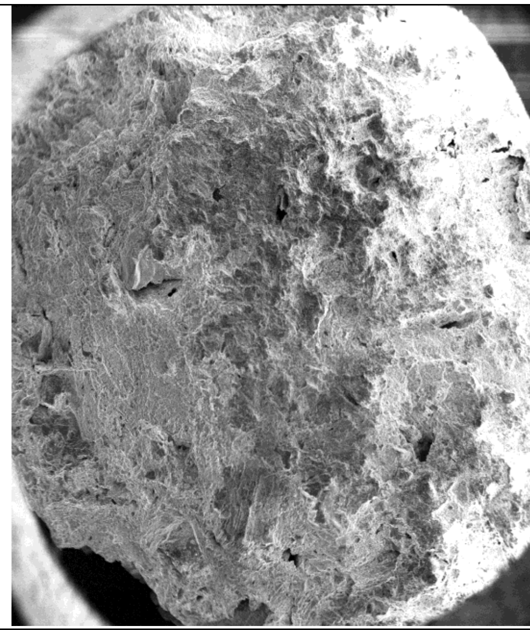
Plate 3: Electron Microscopic view of the clay showing the average diameter of pore (dark spots) at an average of 150 µm but with more pores about 11 pores in1.6x10^{7} $(\mu m)^2$	Plate 4: Electron Microscopic view of the clay showing the average diameter of pore (dark spots) at an average of 150 µm about 5 pores in1.6x10^{7} $(\mu m)^2$

Figure 2: Electron microscopic view. Plates 3 and 4.
Source: Elaborated by the authors.

3. Results and Discussion

The result of emitted water is shown in figure 1. From the water discharge test conducted by connecting the emitter to the discharge end of a water-hose the 80:20 treatment showed a discharge of 8.6 x 10^{-6} l/s (approximately 1 liter/day). The corresponding discharges from 70:30, 60:40, 50:50 and 40:60 were 4.3 x 10^{-5} l/s (2 liter/day), 1.6 x 10^{-5} l/s (approximately 4 liter/day), 1.4 x 10^{-5} l/s (approximately 5 liter/day) and 1.2 x10^{-5} l/s (approximately 7 liter/day). The discharge between 15 and 26 hours corresponds to the water requirements of most vegetable crops grown in the southwestern Nigeria. However, for cost effectiveness, it is recommended that this equipment be used for production of okra and pumpkin vegetables. The discharge also was steadier than that of Netafim drip irrigation equipment available in market. Although Netafim system was not designed for Nano irrigation.

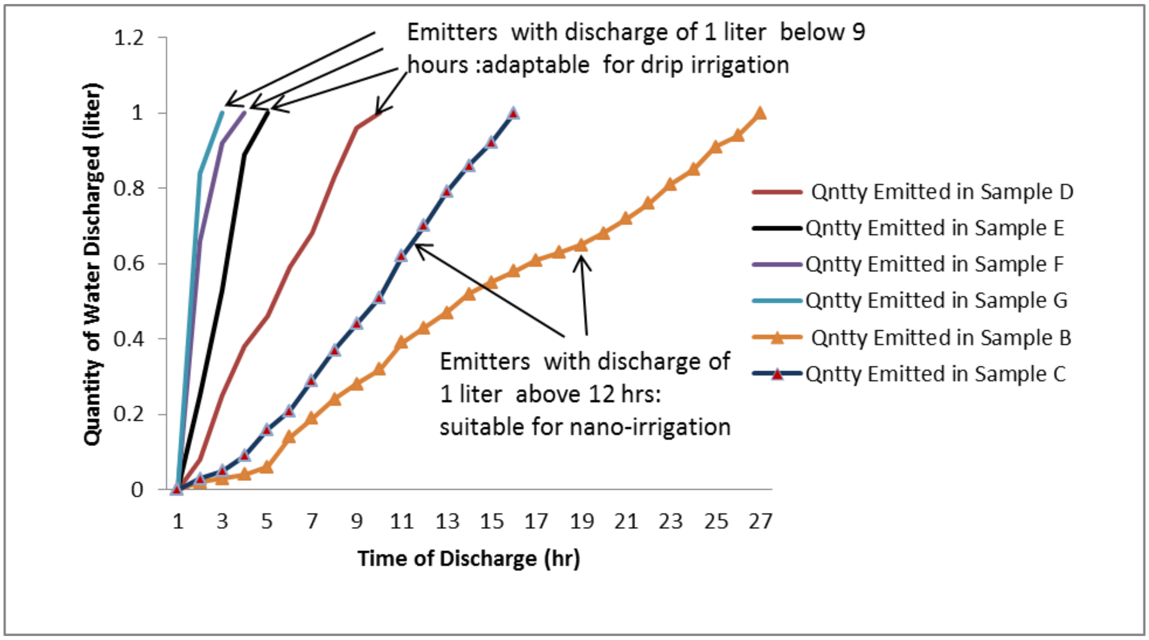

Figure 3: Discharge of water in clay emitters.
Source: Elaborated by the authors

A test conducted in a greenhouse showed that these same emitters were able to sustain potted plants at water deficit condition. The soil moisture in the potted plant showed that water dripped by the emitters contributed minimally to the wetting of the root zone. Evapotranspiration from the potted plants supported with the nano emitters were found to be close to that of the control. This is an evidence that the selected emitters were able to function properly and not adversely affected by the climatic condition prevalent in the environment.

A quantitative assessment of clay work in most clay-molding centers in Ekiti and Ondo states in Southwestern Nigeria showed that the material used for molding a unit of nano-emitter is far less than that used for most of the common wares found in the centers. The material: economic return ratio of nano emitter is over 100 times greater than most of the wares ever produced in those centers. This was attested to by the women who were engaged in the clay work. The clay emitter is far cheaper to produce. Its production is easy for the people in the low income economy. It is quite cheap and readily affordable for the farmers with low income as well. The emitter has very low commercial value, hence it attracts very little or no attention of thieves. Using this material will reduce the risk of vandalism as in the case of many of the irrigation facilities earlier used in this region.

The emitters are buried in the ground close to the root zone of the crop. The chance of losing them during harvesting or after the crop has matured is very high. But since it is easy and less expensive to produce, leaving them in the field after usage is of no threat to the farmer and his business. More so the material is made of earthen material, it will turn to earn with time if left on the field. This will not in anyway cause any environmental hazard as in the case of most synthetic materials used for other irrigation facilities.

4. Conclusion and Recommendation

A clay work was used to improvise emitter that steadily discharged one liter of water over 15 hours. The rate of release of water through the wall of the emitter was such that no water was left to run freely under gravitational force. The rate was enough to leave the surface of the emitter damp. The roots of plant to be irrigated with this type of system can absorb the moisture from the emitter surface without leaving any to free flow. The discharge of this emitter was below the water requirement of most vegetable crops grown in the region where the experiment was conducted. However, for cost effectiveness, the system was recommended for pumpkin and okra whose return can cover the cost of investment. It was also noted that if women engaged in clay work in the Southwestern Nigeria or elsewhere concentrate their effort on clay-nano emitter production, their return on investment will be higher and they will reap better benefit as compared to other wares they use to produce.

It is recommended that this emitter be popularized among vegetable farmers in Nigeria. Also, young Nigerians should be encouraged to explore the opportunities of this investigation and bring innovations into the production of nano emitters. Other materials that could be used to produce emitters without compromising environmental safety, yet make the end products more attractive, effective, less expensive, and durable should be tried.

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Desenvolvimento de sistema de nano irrigação como diafragma de argila para redução de perda de água na produção vegetal em países de baixa renda

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Resumo Os recursos hídricos serão mais afetados pelas mudanças climáticas. Tendo em vista que a agricultura nos países pobres depende enormemente do volume de precipitação, os efeitos das mudanças climáticas serão particularmente maiores nestes países. Todo esforço para melhorar a eficiência do uso da água é valido. Este trabalho apresenta um relatório do desenvolvimento do sistema de nano-irrigação usando argila moldada. O material de argila foi extraído localmente de um depósito próximo à comunidade de Isan-Ekiti, Nigéria. Quantidades variadas de serragem foi misturada à argila antes do molde. Como resultado, encontramos sete diferentes formas de tratar a argila de acordo com as razões de serragem: 100:0, 90:10, 80:20, 70:30, 60:40, 50:50 e 40:60. As amostras foram submetidas a sundagem e mais tarde foram disparadas no forno a 700 o C. Este processo ajudou a reforçar os moldes e eliminar os *burnouts* de serragem. A partir do teste de descarga de água realizado através da conexão do emissor à extremidade de descarga de uma mangueira de água, o tratamento de 80:20 apresentou alta de 8,6 x 10-6 l / s (aproximadamente 1 litro / dia). As descargas correspondentes de 70:30, 60:40, 50:50 e 40:60 foram 4,3 x 10-5 l / s (2 litros / dia), 1,6 x 10-5 l / s (aproximadamente 4 litros / dia), 1,4 x 10-5 l / s (aproximadamente 5 litros / dia) e 1,2 x 10-5 l / s (aproximadamente 7 litros / dia). Em comparação com a fabricação comercial de *drippers* pela Netafim Ltd, a descarga foi muito mais eficiente na redução da perda de água de irrigação. A amostra de 70:30 foi considerada mais adequada para satisfazer a descarga de quantidade de água equivalente ao requisito de água dos vegetais de abóbora e okra. Isso foi confirmado no experimento de campo realizado com estas culturas. Na plataforma de utilização de materiais, o emissor desenvolvido apresentou um custo-efetivo 100 vezes melhor do que o pote de cozinha, e o retorno econômico para a mulher rural supera em muito o de outros produtos de cerâmica.

Palavras-chave: gestão de recursos hídricos, conflito, uso da água, regionalização de vazão.

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