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Emission Uniformity and Gasoline Pump Fuel Use of a Pressurized Drip Irrigation System as Affected by Operating Pressure, Lateral Run Length and Irrigation Running Time

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Abstract
The emission uniformity (EU) of a pressurized drip irrigation system (PDIS) with pressure compensating in-line emitters was evaluated at varied system operating pressures of 103.42 KPa (15 Psi), 172.37 KPa (25 Psi), 241.32 KPa (35 Psi) and 310.26 KPa (45 Psi), and lateral run lengths of 100 m, 200 m and 300 m. The highest EU (95%) was obtained at 172.37 KPa throughout the three lateral run lengths, while the least EU (91%) was obtained at 241.32 KPa. All the EU values obtained within the test operating pressures were above 90% and this is rated excellent by known standards. The differences in EU values were not statistically significant with respect to the operating pressures and lateral run lengths. Also the fuel consumption rates with respect to varied system operating pressures and lateral run lengths were determined and found to vary among the operating pressures. The highest fuel consumption rate (1.04 l/hr) was obtained at 206.84 KPa while the least (0.43 l/hr) was obtained at 103.42 KPa. The differences in fuel consumption with respect to operating pressures were statistically significant but not significant with respect to lateral run length. It was concluded that PDIS with pressure compensating emitters produce uniform EU irrespective of undulating terrains where uniformity of application can be adversely affected by gravitational effects.
Keywords: *Emission uniformity, gasoline pump fuel use, drip irrigation, operating pressure, lateral run length, running time*

Introduction

Irrigated agriculture has been described as the mainstay of the vast majority of developing and emerging countries. Therefore, access to reliable and affordable irrigation water for agriculture is a crucial factor for the economic development of the country (Energypedia, 2019). Manual lifting of irrigation water significantly reduces the scope of cultivation and the efficiency of irrigation. It is characterized by drudgery and subsistence in agricultural production which cannot meet the food demand for the teeming world population. Hence, pressurized systems are required for efficiency in water delivery to the farm units. One of such systems is the pressurized drip irrigation system which demands the use of centrifugal water pumps that are powered with electricity, gasoline, diesel or solar power sources. Drip irrigation is the most efficient water and nutrient delivery system for growing crops. It delivers water and nutrients directly to the plant's roots zone, in the right amounts, at the right time, so each plant gets exactly what it needs, when it needs it, to grow optimally. Drip irrigation is transforming the lives of millions of farmers across the world, enabling higher yields to be produced from any land, while saving water, fertilizer and energy (NETAFIM, 2018).

Emission uniformity (EU) is a measure of how evenly water is applied throughout a specified area. This measurement is essential for scheduling irrigations efficiently. EU is considered an important indicator of irrigation system performance because high levels of EU suggest a very efficient system - more efficient use of water and maximized crop health. It is the goal of every grower to achieve high levels of water use efficiency because it can lead to lower production costs and increased profit margins (RCWD, 2018).

In the absence of reliable electricity supply due to lack of grid connection or intermittent service, farmers in developing countries often rely on gasoline or diesel-driven pumps for water abstraction, conveyance and application (Energypedia, 2019). Gasoline or diesel pump gives the operator room for varying the engine speed within certain limits and thereby vary the pump output. The perspective of grid extension and the establishment of uninterrupted and affordable electricity supply into rural areas is a distant vision in many of these countries (Energypedia, 2019). In Nigeria, power supply has been characterized by low accessibility epileptic and poor transmission and supply. The socio-economic activities in Nigeria have been grossly impacted negatively by insufficient power supply (Ebhota and Tabakov, 2018). It is therefore imperative to investigate the fuel consumption of the common pumps that farmers use for irrigation. This is required in determining the overall input cost of the farm enterprise to determine the profitability of the irrigated farm business. For gasoline or diesel powered pumps, the energy required to pump irrigation water for crop production is measured in terms of fuel use. Energy use depends on the amount of water pumped and on the fuel required to pump each unit of water (Smajstrla et al., 2002).

The pump manufacturers often indicate the engine horsepower and fuel consumption of gasoline pumps, however, this only indicates the test data based on laboratory tests. The pump fuel consumption evaluation would be necessary to reflect the actual conditions of use as influenced by environmental factors such as altitude, ambient temperature, engine accessories (Curley and Knutson, 1992).

The objectives of this study are: i. to determine the emission uniformity of a pressurized drip irrigation system as affected by the system operating pressure and length of lateral run, ii. to evaluate the fuel consumption of a gasoline powered water pump as affected by the system operating pressure, irrigation running time and length of lateral run.

Materials and Methods

Description of Experiments

The experiment for determining the pressurized drip irrigation system emission uniformity (experiment 1) was designed with two factors, namely pump operating pressure (P) and lateral run length (L) while that for determining the gasoline pump fuel consumption (experiment 2) was designed with pump operating pressure (P), lateral run length (L) and irrigation running time (T). The pressure range used for the test was in compliance with the dripline manufacturer’s pressure specification for operating the driplines. These pressures were given by the manufacturer in units of Pounds per square inch (Psi). Conversion of the pressures was subsequently done to the standard international (SI) unit. The manufacturer’s minimum operating pressure is 12 Psi (82.74 KPa) while the maximum is 50 Psi (344.74 KPa) [2].

For experiment 1, there are four P values: P_1 = 103.42 KPa (15 Psi), P_2 = 172.37 KPa (25 Psi), P_3 = 241.32 KPa (35 Psi) and P_4 = 310.26 KPa (45 Psi), while there are three L values: L_1 = 100m, L_2 = 200m and L_3 = 300m. Hence, there are 4 x 3 = 12 treatments in experiment 1 as shown in Table 1(a).

For experiment 2, there are three factors namely: P, L and T. The symbols are as earlier defined. P has three values: P_1 = 103.42 KPa (15 Psi), P_2 = 155.13 KPa (22.5 Psi), P_3 is 206.84 KPa (30 Psi). L has three values: L_1 = 100 m, L_2 = 200m, L_3 = 300 m. T has five values: T_1 = 5 minutes, T_2 = 10 minutes, T_3 = 15 minutes, T_1 = 20 minutes, T_1 = 25 minutes. Total number of treatments is 3 x 3 x 5 = 45 (Table 1(b)).

The study was carried out as an open field drip irrigation experiment at Kaduna, Nigeria (latitude $10^0 36^/$N and longitude $07^0 25^/$E).

Description of the Irrigation System

Irrigation was carried out by means of a pressurized drip irrigation system comprising a ground water source (borehole), an overhead reservoir, a gasoline pumping unit, mains, submains, filter, pressure gauge, laterals and accessories.

The mains and submains, made of polyvinylchloride (PVC), are of diameters 50.8mm and 25.5mm, respectively. The laterals are black oval poly tubing drip lines of diameter 12.7 mm with pressure compensating in-line drippers (Figure 1) fitted at intervals of 45.72cm in the tubings.

Table 1 (a): Description of experiment 1

Treatment	Tag	Treatment description	
		Operating pressure, P (KPa [Psi])	Lateral run length, L (m)
$T_1 1$	P_1L_1	103.42 [15]	100
$T_1 2$	P_1L_2	103.42 [15]	200
$T_1 3$	P_1L_3	103.42 [15]	300
$T_1 4$	P_2L_1	172.37 [25]	100
$T_1 5$	P_2L_2	172.37 [25]	200
$T_1 6$	P_2L_3	172.37 [25]	300
$T_1 7$	P_3L_1	241.32 [35]	100
$T_1 8$	P_3L_2	241.32 [35]	200
$T_1 9$	P_3L_3	241.32 [35]	300
$T_1 10$	P_4L_1	310.26 [45]	100
$T_1 11$	P_4L_2	310.26 [45]	200
$T_1 12$	P_4L_3	310.26 [45]	300

The total length of laterals used in the experiment was 300m. The connections were made possible by the use of connectors and accessories such as Permaloc tees, elbows, bushings, reducers, end caps, filters, valves and pressure gauge. The set-up of the drip irrigation system is shown in Figure 2.

The pumping unit comprised a 1.5 horsepower Honda WP 30 X, Type DF 3 gasoline powered water pump of port connection diameter 80 mm, with design discharge delivery 1000 l/minutes, total head of 30 m and power speed, 3600 rpm. The gasoline pump was newly supplied and had only been run for six hours during the pump initial functionality test. The pump delivered water from the reservoir to the irrigation (Figure 3). The pump was selected for the energy requirement evaluation because it is the common pump used for surface irrigation practice by farmers in the locality.

Table 1(b): Description of experiment 2

Treatment	Tag	P (KPa)	L (m)	T (min)
$T_2$1	$P_1L_1T_1$	103.42	100	5
$T_2$2	$P_1L_1T_2$	103.42	100	10
$T_2$3	$P_1L_1T_3$	103.42	100	15
$T_2$4	$P_1L_1T_4$	103.42	100	20
$T_2$5	$P_1L_1T_5$	103.42	100	25
$T_2$6	$P_1L_2T_1$	103.42	200	5
$T_2$7	$P_1L_2T_2$	103.42	200	10
$T_2$8	$P_1L_2T_3$	103.42	200	15
$T_2$9	$P_1L_2T_4$	103.42	200	20
$T_2$10	$P_1L_2T_5$	103.42	200	25
$T_2$11	$P_1L_3T_1$	103.42	300	5
$T_2$12	$P_1L_3T_2$	103.42	300	10
$T_2$13	$P_1L_3T_3$	103.42	300	15
$T_2$14	$P_1L_3T_4$	103.42	300	20
$T_2$15	$P_1L_3T_5$	103.42	300	25
$T_2$16	$P_2L_1T_1$	155.13	100	5
$T_2$17	$P_2L_1T_2$	155.13	100	10
$T_2$18	$P_2L_1T_3$	155.13	100	15
$T_2$19	$P_2L_1T_4$	155.13	100	20
$T_2$20	$P_2L_1T_5$	155.13	100	25
$T_2$21	$P_2L_2T_1$	155.13	200	5
$T_2$22	$P_2L_2T_2$	155.13	200	10
$T_2$23	$P_2L_2T_3$	155.13	200	15
$T_2$24	$P_2L_2T_4$	155.13	200	20
$T_2$25	$P_2L_2T_5$	155.13	200	25
$T_2$26	$P_2L_3T_1$	155.13	300	5
$T_2$27	$P_2L_3T_2$	155.13	300	10
$T_2$28	$P_2L_3T_3$	155.13	300	15
$T_2$29	$P_2L_3T_4$	155.13	300	20
$T_2$30	$P_2L_3T_5$	155.13	300	25
$T_2$31	$P_3L_1T_1$	206.84	100	5
$T_2$32	$P_3L_1T_2$	206.84	100	10
$T_2$33	$P_3L_1T_3$	206.84	100	15
$T_2$34	$P_3L_1T_4$	206.84	100	20
$T_2$35	$P_3L_1T_5$	206.84	100	25
$T_2$36	$P_3L_2T_1$	206.84	200	5
$T_2$37	$P_3L_2T_2$	206.84	200	10
$T_2$38	$P_3L_2T_3$	206.84	200	15
$T_2$39	$P_3L_2T_4$	206.84	200	20
$T_2$40	$P_3L_2T_5$	206.84	200	25
$T_2$41	$P_3L_3T_1$	206.84	300	5
$T_2$42	$P_3L_3T_2$	206.84	300	10
$T_2$43	$P_3L_3T_3$	206.84	300	15
$T_2$44	$P_3L_3T_4$	206.84	300	20
$T_2$45	$P_3L_3T_5$	206.84	300	25

Figure 1: Cut section of a lateral showing pressure compensating in-line drippers

Determination of Emission Uniformity of the Drip System

The uniformity of the drip irrigation subunits was determined by means of the methodology described by Merriam and Keller (1978). In each of the laterals, four emitters were selected in four different positions along each lateral; at the beginning, quarter, half and end of the lateral length. For each test, the

Figure 2: Set-up of the drip irrigation system

Figure 3: Gasoline pump delivering water from reservoir to the irrigation area

operating pressure was measured by means of a pressure gauge which was positioned after the filter at the junction where the submains take off from the mains. The emissions from the emitters were collected by means of catch-cans at exactly three minutes for each test and the volume of water emitted were measured with graduated measuring cylinders. These data were used to calculate the average discharge from each emitter, and hence, the emission uniformity (EU) as expressed by Keller and Karmeli, 1975) is:

$$EU = \frac{q_{25}}{\bar{q}} \times 100 \qquad (1)$$

Where,

q_{25}: average discharge of 25% of the emitters with the lowest flow (l/h);

$\bar{q}$: average discharge of all the emitters (l/h)

Determination of Pump Fuel Use

The gasoline consumption was determined as a function of three factors: the pump operating pressure, the irrigation running time and the lateral run length. At the start of each run, the fuel tank was filled to capacity. The fuel consumed after each run was hence determined by measuring the volume of gasoline required to refill the tank. A calibrated cylinder was used for this purpose.

Results and Discussion

Emission Uniformity

The emission uniformity results (Figure 5) show that the least EU value is 91%, at 241.32 KPa while the highest value is 95%, at 172.37 KPa. All the EU values are above 90%, a rating considered excellent by ASAE standard (ASAE, 1996). The highest EU was consistent at 100 m, 200 m and 300 m running length of the laterals. The test statistic result indicates that the variation in EU values among the varied operating pressures was not significant (Calculated F value (2.76) < the critical F value (4.07) at P (0.1114)). Also, EU did not vary significantly among the lateral run lengths (Calculated F value (0.3857) < the critical F value (4.26) at P (0.6907)). However, the system should be operated at the pressure that produced the highest EU at all the lateral run lengths; in this case, 172.37 KPa (25 Psi).

The consistency in EU for the drip line used in this experiment explains the advantage of a pressure compensating (PC) emitters over non-pressure compensating ones. PC emitters maintain the same output at varying water inlet pressures. Therefore, PC drip emitters compensate for uneven terrain, length of supply tube and varying inlet flows. PC drippers facilitate more controlled watering, as each drip emitter performs to a preset flow rate (Drip Depot, 2013). They can simplify the designing of a system and greatly reduce maintenance since they rarely get plugged. Inside the emitter is a flexible diaphragm that regulates the water flow and tends to flush particles from the system (self-flushing) (Drip Works, 2019). Hence, in precision farming where precise data are required for exact input administration, PC emitters should be preferred to the non PC ones.

Gasoline Pump Fuel Use

The gasoline pump fuel use was obtained for each system operating pressure and lateral run length as expressed by the equations of the graphs in Figures 6 – 8. The results showed a significant difference in fuel consumption as the operating pressure increased. Hence, as a fuel saving measure to reduce expenditure on gasoline, the irrigation system should be run only at such lowest operating pressure as permits excellent emission uniformity (EU > 90%). For each fuel use function, the operator can estimate the cost of running the pump by multiplying the consumption by the prevailing price of gasoline per litre in the area.

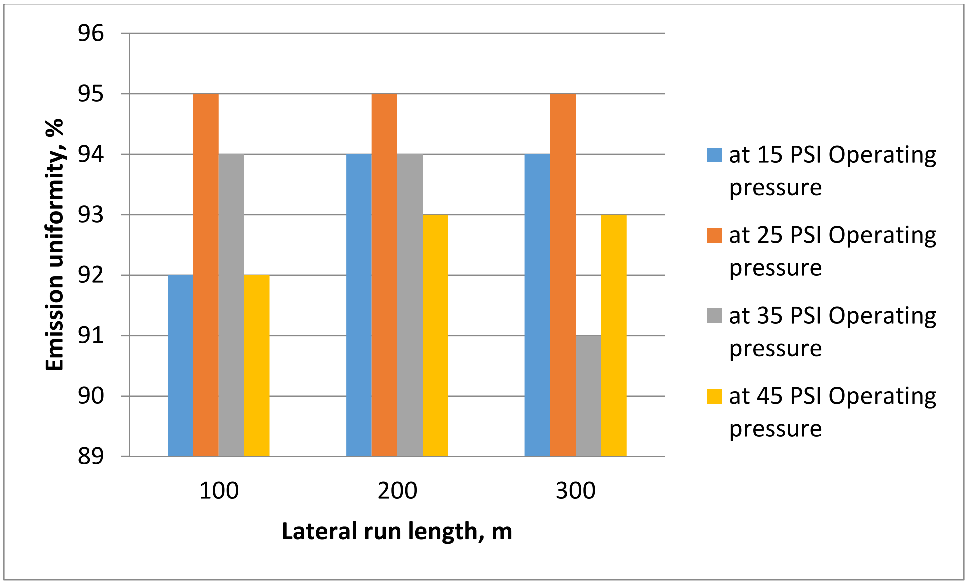

Figure 5: Emission uniformity at varied lateral run length and operating pressures

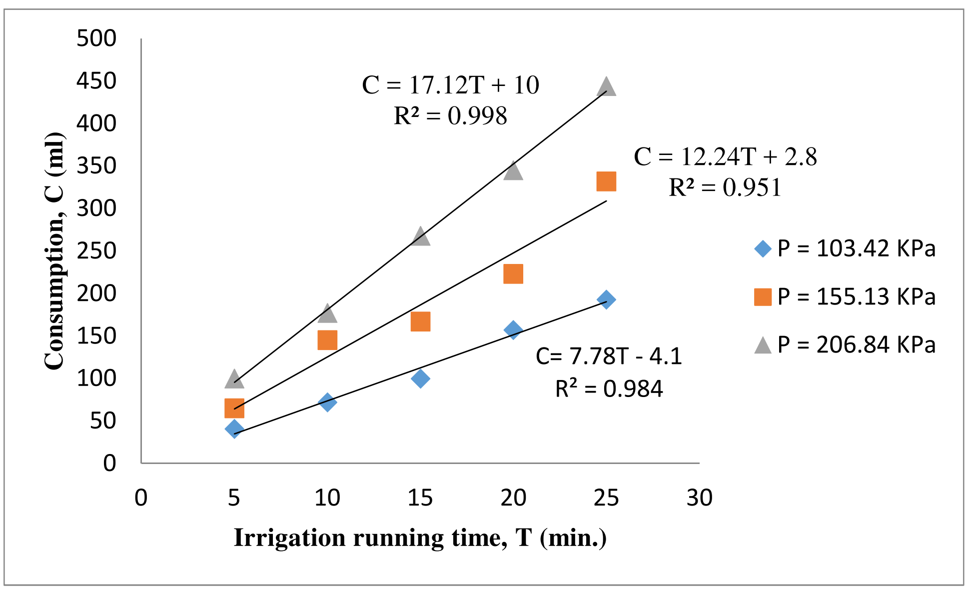

Figure 6: Fuel consumption at L = 100m as a function of operating pressure and irrigation running time

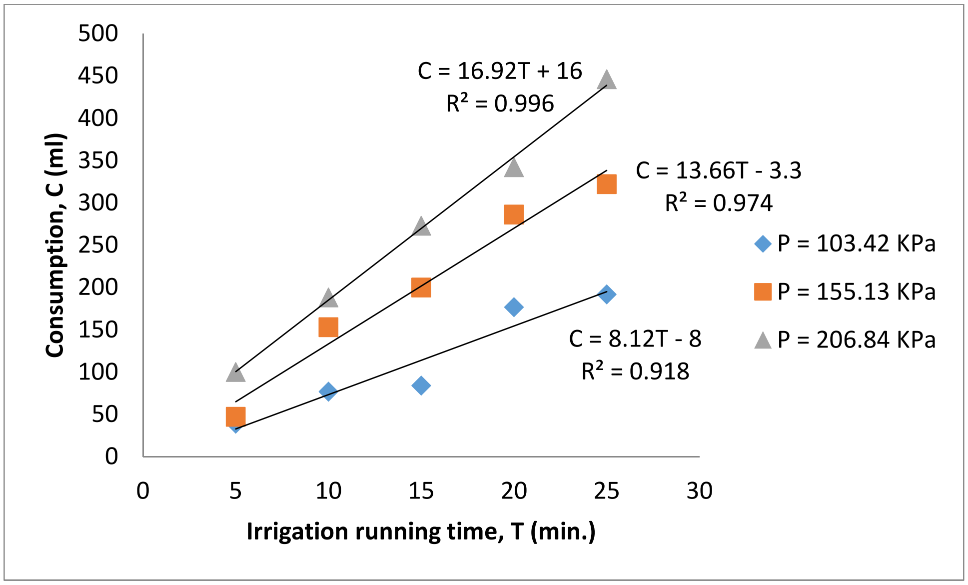

Figure 7: Fuel consumption at L = 200m as a function of operating pressure and irrigation running time

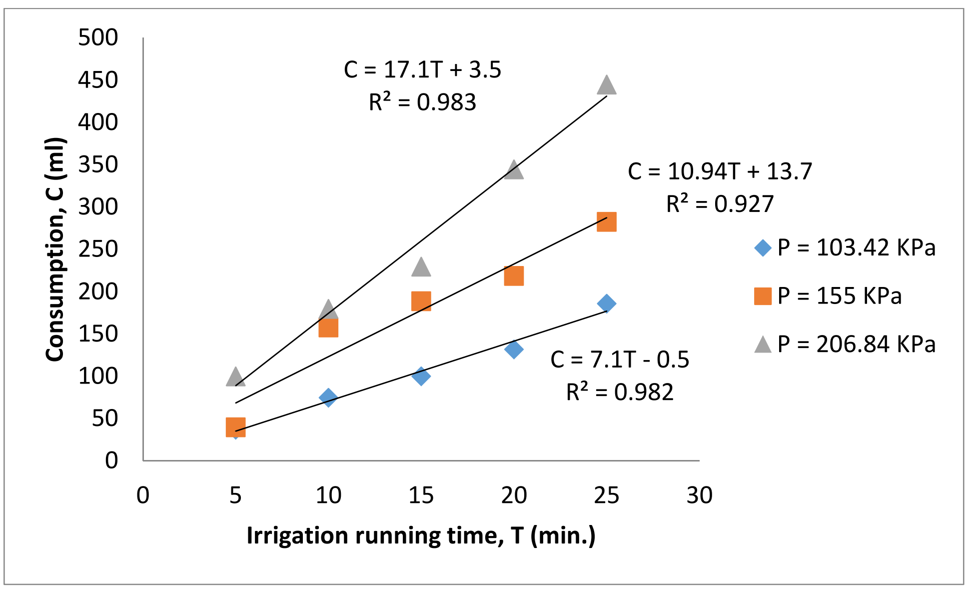

Figure 8: Fuel consumption at L = 300m as a function of operating pressure and irrigation running time

An analysis of variance of fuel consumption as affected by lateral run length (Table 2) showed that there was no significant difference in the fuel use as long as the same operating pressure is maintained.

Table 2: Analysis of variance of fuel consumption as affected by lateral run length

Statistical parameter	Test statistic		
	Operating pressure (KPa)		
	103.42	155.13	206.84
$F_{calc.}$	0.0229	0.8486	0.0069
$F_{crit.}$	3.8853	3.8853	3.8853
P-value	0.9774	0.9192	0.9931
Conclusion	NS	NS	NS

F_{calc}: Calculated F-value; $F_{crit.}$: Critical F-value; NS: Not significant

Conclusion

The emission uniformity (EU) of a pressurized drip irrigation system was investigated at various system operating pressures within the manufacturer's specifications, as well as at varied lateral run lengths. The system comprised drip line tubing with in-line pressure compensating emitters, powered by a new gasoline water pump of known specifications. The EU values were excellent within the specified operating pressures and there were no significant differences in the EU values either due to the operating pressure or lateral run length. It is therefore concluded that pressurized drip irrigation with pressure compensating emitters is ideal in situations that require precision water metering for high water application efficiency. It is also more fitted for drip irrigation on undulating terrains where uniformity of application can be adversely affected by gravitational effects.

The pressurized drip irrigation system is often, of necessity, powered by a water pump (except by gravity from a height that is sufficient enough to produce the required operating pressure). Farmers in the study area commonly use gasoline water pump for pumped irrigation. Hence, a gasoline water pump has been adopted for this experiment and the fuel use functions have been developed as a guide for estimating gasoline fuel use and cost. The fuel use was generally found to increase with increasing operating pressure and it is recommended that the system should be operated at the least operating pressure that guarantees excellent EU so as to minimize fuel consumption, and hence, cost of fuel use.

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