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To cite this article: D O Onwuegbunam *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **445** 012024

View the article online for updates and enhancements.

Effects of operating pressure, lateral length and irrigation period on the fuel consumption of a centrifugal pump in a pressurized drip irrigation system

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Abstract. The fuel consumption rates of a centrifugal water pump was evaluated with respect to varied system operating pressures and lateral lengths and irrigation period in a pressurized drip irrigation system (PDIS). The fuel consumption rates were 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 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.

1 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 [1]. 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 increasing 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 [2].

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 [1]. 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 [1]. 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 [4]. 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 [5].

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 [6].

The objectives of this study is to evaluate the fuel consumption of a gasoline powered water pump as affected by the system operating pressure, irrigation period and lateral length.

2. Materials and Methods

2.1 Description of the Experiment
The experimental factors comprise: Operating pressure (P), Lateral run length (L) and Irrigation period (T). P has three values: P_1 = 103.42 KPa (15 Psi), P_2 = 155.13 KPa (22.5 Psi), P_3 = 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).

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

2.2 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. 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%) [7,8 and 9]

The mains and submains, made of polyvinylchloride (PVC), are of diameters 50.8 and 25.5 mm, respectively. The laterals are black oval poly tubing drip lines of diameter 12.7 mm with pressure compensating (PC) in-line drippers fitted at intervals of 45.72 cm in the tubings. These emitters compensate for uneven terrain, length of supply tube and varying inlet flows and facilitate more controlled watering, as each drip emitter performs to a preset flow rate [10]. 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) [11]. Hence, in precision farming where precise data are required for exact input administration, PC emitters should be preferred to the non PC ones.

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 1.
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 2).

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. Description of experiment

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

Figure 1. Set-up of the drip irrigation system

Figure 2. Gasoline pump delivering water from reservoir to the irrigation area

2.3 Determination of Pump Fuel Use
The gasoline consumption was determined as a function of three factors: the pump operating pressure, the irrigation period and the lateral 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.

3. Results and Discussion

3.1 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 3–5. The results showed a significant difference in fuel consumption as the operating pressure increased. The emission uniformity (EU) for each of the tests was above 90%. 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%) [7,8 and 9]. 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.
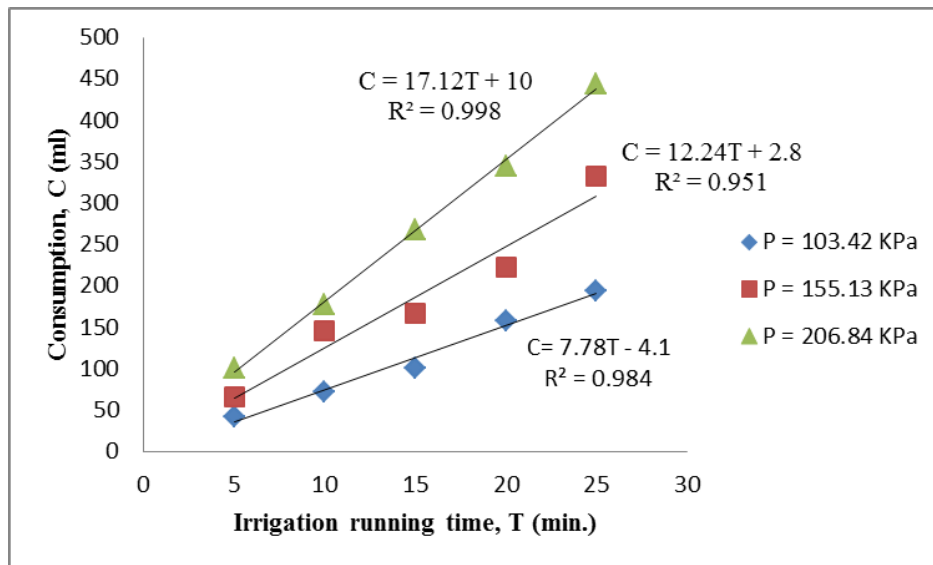
Figure 3. Fuel consumption at L = 100 m as a function of operating pressure and irrigation running time
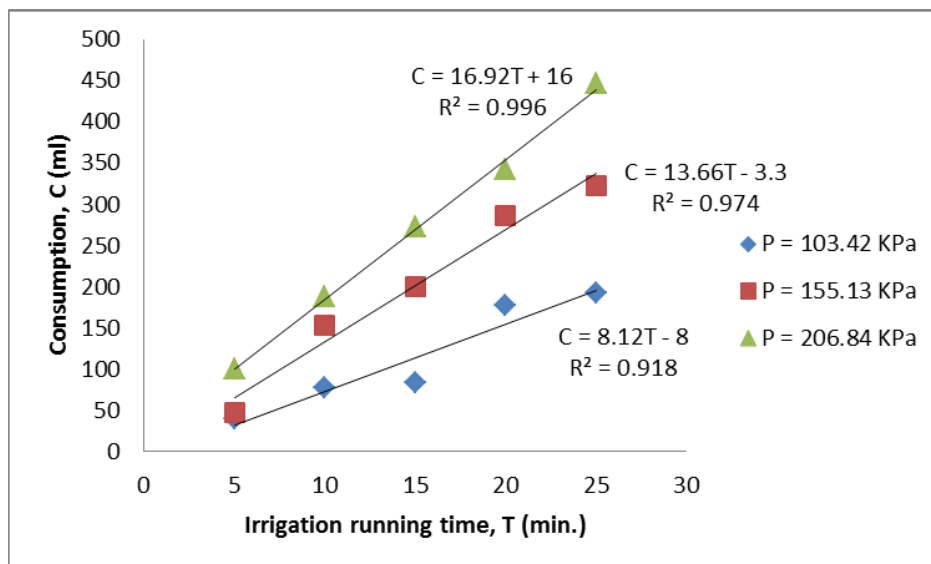
Figure 4. Fuel consumption at L = 200 m as a function of operating pressure and irrigation running time
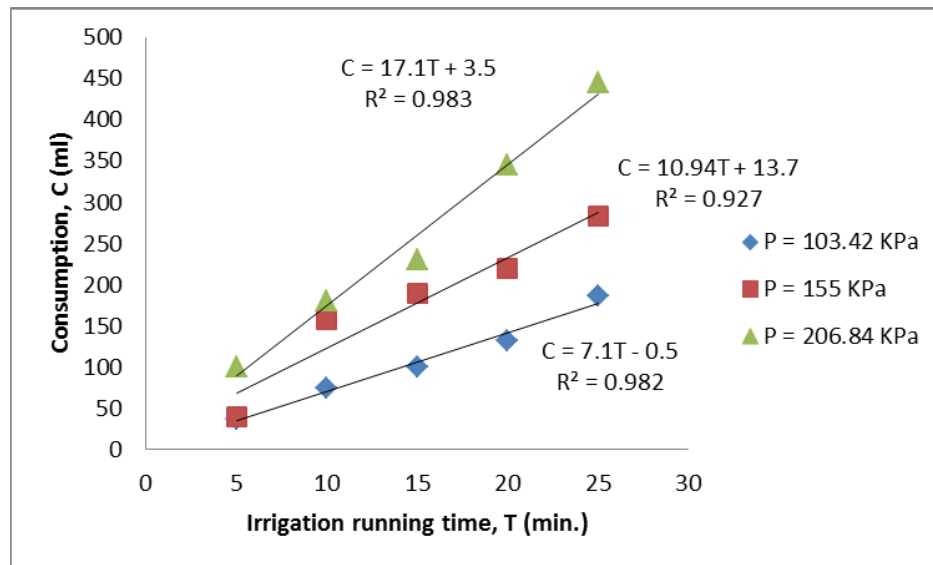
Figure 5. Fuel consumption at L = 300 m as a function of operating pressure and irrigation running time

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

4. Conclusions

The fuel use of the gasoline powered centrifugal pump was generally found to increase with increasing operating pressure. It is recommended that PDISs should be operated at the least operating pressure that guarantees excellent EU so as to minimize fuel consumption, and hence, cost of fuel use. The results obtained from this study would serve as a guide for estimating gasoline fuel use and cost under precision water management in drip irrigation of arables and horticultural crops.

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