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Dynamic Performance of Agricultural Tractor Fuelled with Karanja Biodiesel Blends for Tillage Operation

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Abstract

This paper reveals the scope for utilization of biodiesel blends with petrol diesel in agricultural tractor for tillage operations for addressing the problem of fuel crisis. The blends were prepared on volume basis in proportions of 20:80, 40:60, 60:40 and designated as B20, B40, B60 respectively and their physico-chemical properties were determined/measured and compared with petro-diesel (B0). The performance of agricultural tractor in terms of specific draft, drawbar power, fuel consumption and fuel efficiency were assessed following the RNAM test codes and the exhaust emission of the tractor was also analysed using exhaust gas analyzer at three selected forward speeds viz., 2.5, 3.5 and 4.5 km h-1 during tillage operations. The results revealed that the specific draft and drawbar power of tractor were not affected by the blends but significantly affected by forward speed. However, the fuel consumption and fuel efficiency were affected significantly by both the blends and forward speed of operation. The rate of increase in the emission levels of CO and NOX were the direct function of forward speed. The emission level of CO decreased with the blends of biodiesel while, the NOX emissions increased with the increase in biodiesel blends. Among the blends tested, B20 had very similar performance with petro diesel in terms of specific draft, drawbar power and exhaust gas emission, thus has the scope for utilization as fuel in agricultural tractor for tillage operations.

Keywords: Agricultural tractor, Biodiesel blends, Drawbar power, Exhaust emission, Fuel consumption and Tillage operation

Introduction

Petroleum is the single largest source of energy consumed by the world's population and global demand is predicted to increase 40 per cent by 2025 (Anon, 2005). One of the significant routes to tackle the problem of increasing prices and pollution problems of petroleum fuels is the use of green fuels such as biodiesel. Biodiesel is an attractive alternative fuel to petro-diesel mainly because it is renewable, biodegradable and environmental friendly. Also this can be produced from common feed stocks, such as vegetable oils and animal fats. In most parts of the world it is being produced from the feedstocks that are essentially edible. Therefore, in the developing countries, including India, it is potential to produce biodiesel from non-edible oils and can be extensively grown in the waste lands (Baiju *et al*, 2009). The common non-edible oils available in India are karanja, jatropha, neem, simarouba, etc. (Anon, 2003).

The use of raw edible or non edible oils in diesel engine has limited scope because these possess higher viscosity, cloud and pour point as compared to diesel fuel (Jones and Peterson, 2003). The negative effects of raw vegetable oil can be reduced or eliminated through transesterification process in that methyl/ethyl esters are produced by reacting the raw oil with methyl/ethyl alcohol in the presence of a catalyst (Avinashkumar and Rajamanoharan, 2009). However, blends of mineral diesel fuel and 20 - 50 per cent of vegetable oil can be used in diesel engines (Forson *et al*, 2004).

In most of the previous studies, biodiesel was usually tested on single-cylinder stationary engines. The use of B5, B10, B15, and B20 blends did not affect the engine torque and power, but did cause a reduction in the fuel consumption. While; the use of B40, B60, B80 and B100 reduced the torque and power output of the engine and increased the fuel consumption (Stalin and Prabhu, 2007). The dynamic performance of 74.56 kW agricultural tractor using spent oil biodiesel blends revealed that the specific fuel consumption of tractor operated on 100 per cent biodiesel was increased on average by 18 per cent in comparison to the petro-diesel (Soranso *et al*, 2008). The application of different methyl ester blends in proportion of B10, B20, B30, B50, B75 and B100 obtained from mixture of 75 per cent sunflower oil and 25 per cent cooking oil used in agricultural tractor (Kubota) of 19.7 kW rated horsepower showed no significant reduction in power output and torque with blends below 50 per cent, however fuel consumption with biodiesel were higher than that of diesel except the blends up to 30 per cent (Milan *et al*, 2010). The analysis of exhaust gas emission of the tractor using B0, B20 and B100 blends during ploughing and rotary tilling in the paddy fields indicated that the diesel fuel combustion discharged the maximum amount of CO_2 (8.7 per cent), followed by B20 (8 per cent), and B100 (7.8 per cent). The NO_X concentration was maximum (815.1 ppm) for B100 while it was 775.8 ppm for diesel (Kim *et al*, 2010).

Most of the research on biodiesel use and exhaust emissions were conducted in laboratories under simulated condition by applying a predetermined load cycle. Most of the tested engines were heavy-duty highway engines, but little attention was given to off-road engines, especially in real-time in-use conditions (Anon, 2002). Although biodiesel is derived from agriculture and many of studies were conducted by agricultural engineers, in India, virtually no documentation on exhaust emissions from either petroleum or biodiesel fuel use in agricultural tractor. Few investigations have been carried out in agricultural and forestry tractors, that's to be in real field conditions.

The objective of this study was to investigate the performance and exhaust emission of agricultural tractor fuelled with blends of karanja biodiesel *viz.*, B20, B40 and B60 under real field conditions.

Materials and Methods

Karanja (*Pongamia pinnata* L) is the forest based tree borne non-edible oil with a production potential of 1,35,000 mt in India. Previous researchers have reported that lower blends of karanja biodiesel were in close comparable with diesel fuel in respect of fuel properties and performance of IC engine under laboratory conditions (Srivastava *et al*, 2008 and Ramchandra *et al*, 2011).

Karanja biodiesel was procured from Indus Biodiesel Plant in Shimoga District, Karnataka, India. The blends of biodiesel were selected with an increment of 20 per cent of value up to 60 percent blends and designated as B20, B40 and B60 respectively. The petro-diesel is designated as B0. The blends were prepared on volume basis in the proportion of 20:80, 40:60 and 60:40 per cent of biodiesel and petro-diesel.

Fuel properties

The overall flammability and quality of selected blends were analysed by determining various physical and chemical properties as per ASTM standard procedures. The density of the fuel was determined by pycnometer. The kinematic viscosity of the test fuels was determined by using a constant temperature bath Redwood viscometer. An adiabatic oxygen bomb calorimeter was used to determine the calorific value of the fuels. The Pensky Marten's open cup flash and fire point apparatus was used to the determine flash and fire points of the selected blends of biodiesel and petro-diesel. The fuel sample was titrated against 0.25 N sodium hydroxide and 2 ml of phenolphthalein indicator to determine free fatty acid content of test fuels. All the tests were repeated thrice for all the blends and their average values were reported.

Tractor and equipments

A 50 hp agricultural tractor (2WD Mahindra 585DI) with rated engine speed of 2600 rpm and nominal PTO output of 42 hp was selected for evaluation. Tillage operations (ploughing and harrowing) were carried out to assess the performance of tractor at various forward speeds. The matching equipments *viz.*, a two bottom mould board plough of 0.9 m width and off set disc harrow of 1.66 m width were selected for tillage operations to suite local soil conditions.

Field experimentation

The complete experiment was conducted in single plot to avoid much variation in the field conditions. Tillage operations were conducted at three selected speeds of 2.5 (S1), 3.5 (S2) and 4.5 (S3) km h^{-1}. The forward speed of tractor was calibrated to the desired speed for individual blends of biodiesel by adjusting engine throttle position and gear setting. The depths of ploughing and harrowing operations were maintained at 0.20 m and 0.15 m respectively, throughout the field by a hydraulic lever at constant position, to avoid much variation on the engine loading. Each treatment was tested on an area of 0.09 hectares (10×90 m^2) laid randomly in the field and it was divided into three main blocks for the experiment. A 3*4 asymmetric factorial complete randomized block design was used for field layout.

The tractor performance was evaluated for specific draft, drawbar power, fuel consumption and fuel efficiency for both primary and secondary tillage operations by following standard procedures given in RNAM technical series 12 (Anon, 1983). Draft of the implements was measured by rolling method as per RNAM standard test codes by using digital dynamometer (Syscon Instrumentation Pvt. Ltd. Banglore, India) with an accuracy of 1 kg. The average values were used for computing the specific draft and drawbar power of tractor for selected blends at different speeds. The measured quantity of fuel was filled in the auxiliary fuel tank that was mounted on the tractor with a set of valves that control the flow of fuel to the filter. A pulse type flow meter (DMF 50) was installed in fuel line of tractor between the auxiliary fuel tank and fuel pump, this measures the volumetric flow rate of fuel consumption (Ali *et al*, 2011). After each experiment, the auxiliary fuel tank was made empty by switching bypass value and then the tank was filled with new blend. The tractor was then operated at high idle for about 15 minutes which ensured to replace the older one with new blend in fuel line. The fuel efficiency was determined as the drawbar power produced per unit volume of the fuel consumed and expressed in MJ l^{-1} (Li *et al*, 2006). The performance parameters were statistical analysed using design expert – 7 version software.

Emission characteristics

Emission characteristics of the tractor were analyzed during primary and secondary tillage operations for all the blends tested by using a gas analyser (KM900 Plus analyser, M/s Nevco Engineers Pvt. Ltd., New Dehli, India). The probe (sensor) of the gas analyzer was directly inserted in to the exhaust gas outlet of the tractor, which detects carbon monoxide (CO) and oxides of nitrogen (NOx) present in exhaust gas.

Results and Discussion

Fuel properties

The physico-chemical properties of selected blends of biodiesel are presented in Table 1. The kinematic viscosity of all the blends tested were found to be higher than that of petro-diesel that was maximum for B60 (4.2 cSt) among the selected blends. Similarly, the specific gravity of petro-diesel was 0.824 g cc^{-1} while it was 0.892 g cc^{-1} for B60. It increased as the per cent of biodiesel increased in petro-diesel. The calorific value of B60 blend was found to be 37.42 MJ Kg^{-1} that was 11.08 per cent lesser than the calorific value of petro-diesel (42.43 MJ Kg^{-1}). As the percentage of biodiesel in the blends increased, the calorific value decreased which may be due the presence of more oxygen molecules (Sahoo and Das, 2009). The flash and fire point of selected blends of biodiesel varied from 65 to 104 ºC and were increased as the per cent of biodiesel increased in petro-diesel, that is safe for storage and handling as compared to diesel alone (Sahoo *et al*, 2009). The free fatty acids of blends tested varied from 0.266 to 0.566 per cent and it was absent in petro-diesel. The addition of biodiesel increased the free fatty acid content of the fuel.

Soil conditions

The selected experimental plot comprised of clay loam soil and its moisture content at 20 cm depth was 11 per cent. The bulk density of soil varied from 1.62 to 1.65 g cm^{-3}. The cone index at a depth of 0-10 cm was 1.8 to 2.1 kg cm^{-2} while it was in the range of 3.5 to 3.7 kg cm^{-2} at a depth of 10-20 cm.

Specific draft

The maximum specific draft of 12.29 N mm^{-1} was observed for B0S3 while, it was minimum (7.38 N mm^{-1}) for B20S1 during ploughing operation. During harrowing, the highest specific draft was recorded for B40S3 (5.17 N mm^{-1}) whereas the lowest draft of 3.08 was found for B60S1 (Table 2). It was found that the fuel type did not significantly affect the specific draft, whereas, it was significantly affected by forward speed at 5 per cent level of significance. But the interaction effect of both factors was not significant. This may be due to the fact that the specific draft was affected only by the implement type, width of cut, depth of cut and corresponding soil implement interaction (Kheiralla *et al*, 2004). As the forward speed increased, the specific draft of the implement increased for both the tillage operations that may be attributable to the increase in the draft of the implement at higher speeds.

Drawbar power

The maximum drawbar power of 12.14 kW was obtained for B0S3 while it was minimum (4.05 kW) for B20S1 for ploughing operation. Similarly, the maximum drawbar power of 10.35 kW was recorded for B40S3 while it was minimum (3.42 kW) for B60S1 during harrowing operation.

The drawbar power of tractor was affected by forward speed of operation that may be due to the variation in the draft of the implement for different speeds (Table 3). However, it was not affected by fuel type. The similar results were reported for power and energy requirement of tillage implements (Surendra Singh, 2011).

Fuel consumption

The fuel consumption of agricultural tractor varied from 3.06 to 4.45 l h^{-1} during ploughing operation. While in case of harrowing operation, it varied between 2.47 to 4.43 l h^{-1} (Table 4). The maximum and minimum fuel consumption was recorded for B60S3 and B0S1 respectively for both the field operations. The fuel consumption for B60S3 was increased by 32.18 and 44.24 per cent as compared to B0S1 during ploughing and harrowing operation respectively.

The analysis of the results showed that the fuel consumption of tractor was significantly affected by both the forward speed and fuel type at 5 per cent level of significance (Table 4). The fuel consumption of tractor increased with the increase in per cent of biodiesel in petro-diesel that may be due to the lower calorific value of biodiesel blends as compared to petro-diesel (Li *et al*, 2006).

Fuel efficiency

The maximum fuel efficiency of 10.32 MJ l^{-1} was obtained for B0S3, while it was minimum (4.34 MJ l^{-1}) for B60S1 during ploughing operation. Similar results were found for harrowing operation (Table 5).

The fuel efficiency was affected significantly by all the blends of biodiesel tested at all forward speeds, whereas, their combined effect was not significant at 5 per cent level of significance. As the blends of biodiesel increased, fuel efficiency decreased that was due to the lower calorific value of higher blends. It increased with the increase in forward speeds of tractor, which was due to the higher drawbar power produced by tractor at higher speeds (Kheiralla *et al*, 2004). Among the blends tested, B20 performed comparable with petro-diesel at all the speeds.

Emission characteristics

The emission levels of tractor during the tillage operations were analyzed and are depicted in figures 1 and 2.

The highest CO emission (1499 ppm) was recorded for B0S3 during ploughing, while it was lowest (823 ppm) for B60S1 (Fig. 1 a). The CO emission of all the blends tested increased as forward speed increased. The increase in the per cent of biodiesel decreased the CO emission that may be due to the more number of oxygen molecules present in biodiesel as compared to petro-diesel that helps in complete combustion of biodiesel as compared to petro-diesel fuel[17]. Similarly, CO emission characteristics of tractor during harrowing operation were analysed and showed similar trend as that of ploughing operation but its emission rate was less as compared to ploughing operation for all the speeds irrespective of blends (Fig. 1 b). This may be due to variation in the draft and power generated for both the operations. The similar trend was reported for emission characteristics of Jatropha, Karanja and Polanga based biodiesel as fuel in tractor engine (Sahoo *et al*, 2009).

The NOx emission from the tractor at different forward speeds using selected blends of biodiesel are shown in Fig. 2. It was observed that NOx emission for different blends increased from average value of 279 ppm to 596 ppm as the speed of ploughing operation increased (Fig. 2 a). The NOx emission during harrowing operation was varied from 266 to 509 ppm at all the speeds for selected blends of biodiesel. The maximum NOx emission of (509 ppm) was obtained at S3 for B60 blend while it was minimum (266 ppm) was observed at S1 for B0 fuel (Fig. 2 b). The NOx emissions of all the blends were higher than diesel at all the speeds. It was observed that the NOx emissions were direct function of blends of biodiesel and forward speed. The similar results were reported for emissions of agricultural tractor using soybean biodiesel blends during tillage and drill operations (Li *et al*, 2006).

Conclusions

The effects of biodiesel blending with diesel on performance and emission characteristics of the tractor at different speeds have been investigated and the following specific conclusions were drawn.

- The fuel properties of B20 blend were found to be comparable with the diesel fuel.
- The specific draft and drawbar power of tractor during ploughing and harrowing operations were not affected by the fuel type, but they were significantly affected by the forward speed of the tractor.
- As the per cent of biodiesel increased in petro-diesel, NOx emission also increased but, the emission of CO decreased that may be due the fact that the complete combustion of biodiesel blended fuel reduced the emission of CO.
- B20 performed comparably with the petro-diesel in terms of fuel consumption, fuel efficiency and NOx emission.

Hence, B20 blend of karanja biodiesel may be recommended for use in agricultural tractor as an alternate fuel. However, the long duration trials should be conducted to study the effect of blends of biodiesel on various components of the tractor engine and its performance under the field conditions.

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Table 1. Physico-chemical properties of petro-diesel and selected blends of biodiesel

Types of blends	Calorific value (MJ kg^{-1})	Kinematic viscosity (cSt)	Specific gravity (g cc^{-1})	Flash point (ºC)	Fire Point (ºC)	Free fatty acids (%)
B0	42.43	1.97	0.824	65	70	--
B20	38.65	2.44	0.847	71	73	0.266
B40	37.98	3.17	0.868	88	95	0.433
B60	37.42	4.22	0.892	104	110	0.566

Table 2. Effect of selected blends of biodiesel and forward speed on specific draft (N mm^{-1})

Fuel Blends	Ploughing					Harrowing				
	Forward speeds (kmph)			SEm	CD	Forward speeds (kmph)			SEm	CD
	S1	S2	S3			S1	S2	S3		
B0	7.51	9.67	12.29	0.124	0.363	3.14	4.78	5.05	0.054	0.159
B20	7.38	9.49	12.08			3.16	4.86	5.11		
B40	7.50	9.77	12.23			3.18	4.92	5.17		
B60	7.44	9.55	12.27			3.08	4.82	5.16		
SEm	0.107			0.214*		0.047			0.094*	
CD	0.314			0.629*		0.138			0.276*	

* SEm and CD values of B*S

Table 3. Effect of selected blends of biodiesel and forward speed on drawbar power (kW)

Fuel Blends	Ploughing					Harrowing				
	Forward speeds (kmph)			SEm	CD	Forward speeds (kmph)			SEm	CD
	S1	S2	S3			S1	S2	S3		
B0	4.12	7.43	12.14	0.107	0.314	3.49	7.44	10.10	0.094	0.276
B20	4.05	7.29	11.93			3.51	7.55	10.23		
B40	4.11	7.50	12.07			3.54	7.66	10.35		
B60	4.08	7.33	12.12			3.42	7.49	10.31		
SEm	0.092			0.185*		0.081			0.163*	
CD	0.272			0.544*		0.239			0.478*	

* SEm and CD values of B*S

Table 4. Effect of selected blends of biodiesel and forward speed on fuel consumption (l h^{-1})

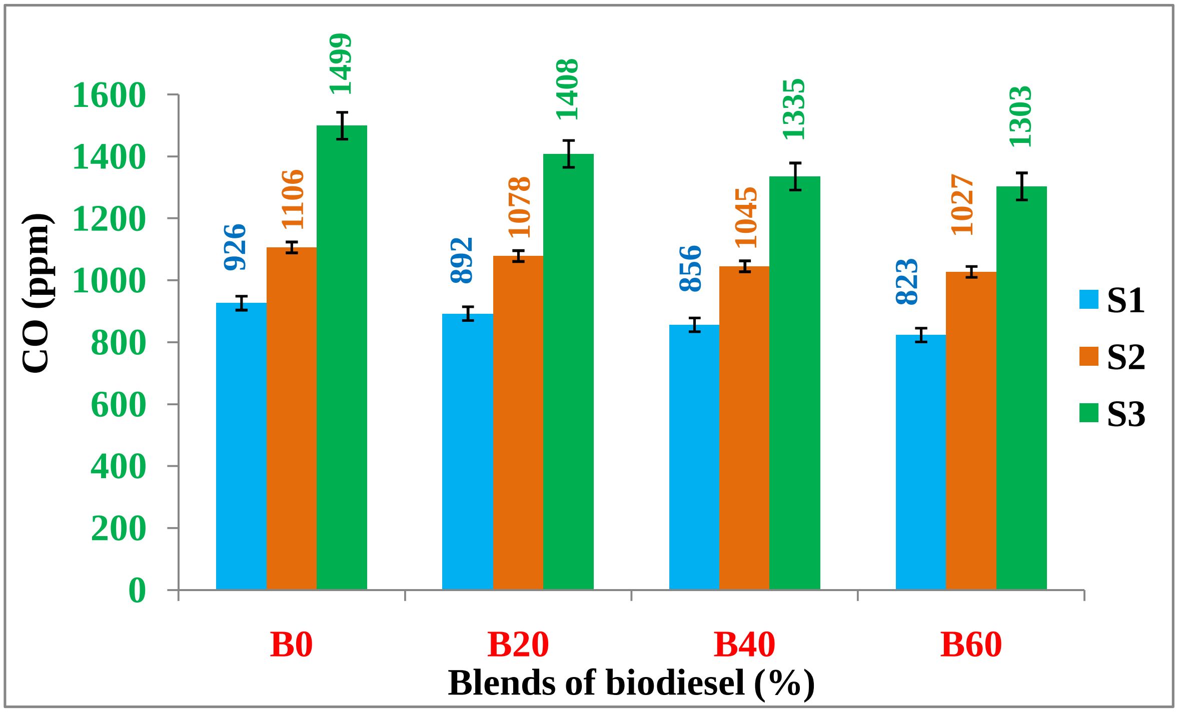
Fuel Blends	Ploughing					Harrowing				
	Forward speeds (kmph)			SEm	CD	Forward speeds (kmph)			SEm	CD
	S1	S2	S3			S1	S2	S3		
B0	3.06	3.55	4.24	0.003	0.010	2.47	3.37	4.05	0.009	0.027
B20	3.15	3.62	4.36			2.58	3.48	4.22		
B40	3.23	3.77	4.45			2.78	3.60	4.31		
B60	3.39	3.85	4.54			3.15	3.67	4.43		
SEm	0.003			0.006*		0.007			0.015*	
CD	0.009			0.018*		0.023			0.046*	

* SEm and CD values of B*S

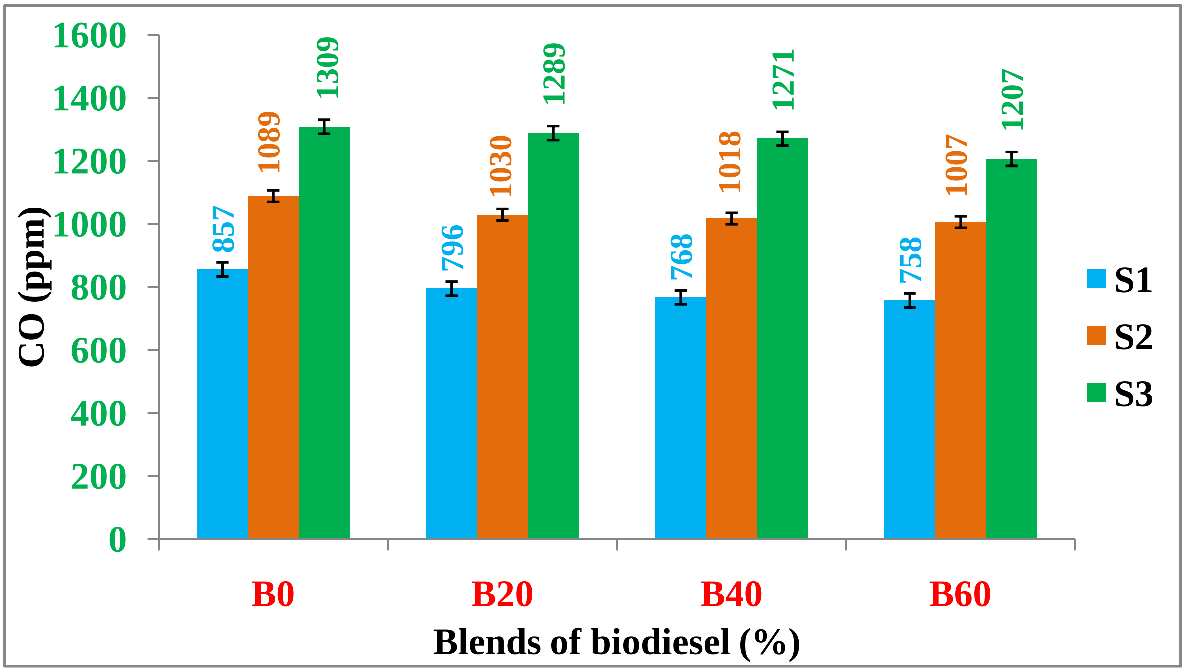
Table 5. Effect of selected blends of biodiesel and forward speed on fuel efficiency (MJ l^{-1})

Fuel Blends	Ploughing					Harrowing				
	Forward speeds (kmph)			SEm	CD	Forward speeds (kmph)			SEm	CD
	S1	S2	S3			S1	S2	S3		
B0	4.85	7.53	10.32	0.094	0.275	5.09	7.94	8.99	0.096	0.281
B20	4.62	7.26	9.87			4.91	7.82	8.72		
B40	4.58	7.17	9.79			4.58	7.65	8.64		
B60	4.34	6.86	9.60			3.90	7.35	8.38		
SEm	0.081			0.162*		0.083			0.166*	
CD	0.238			0.477*		0.244			0.488*	

* SEm and CD values of B*S

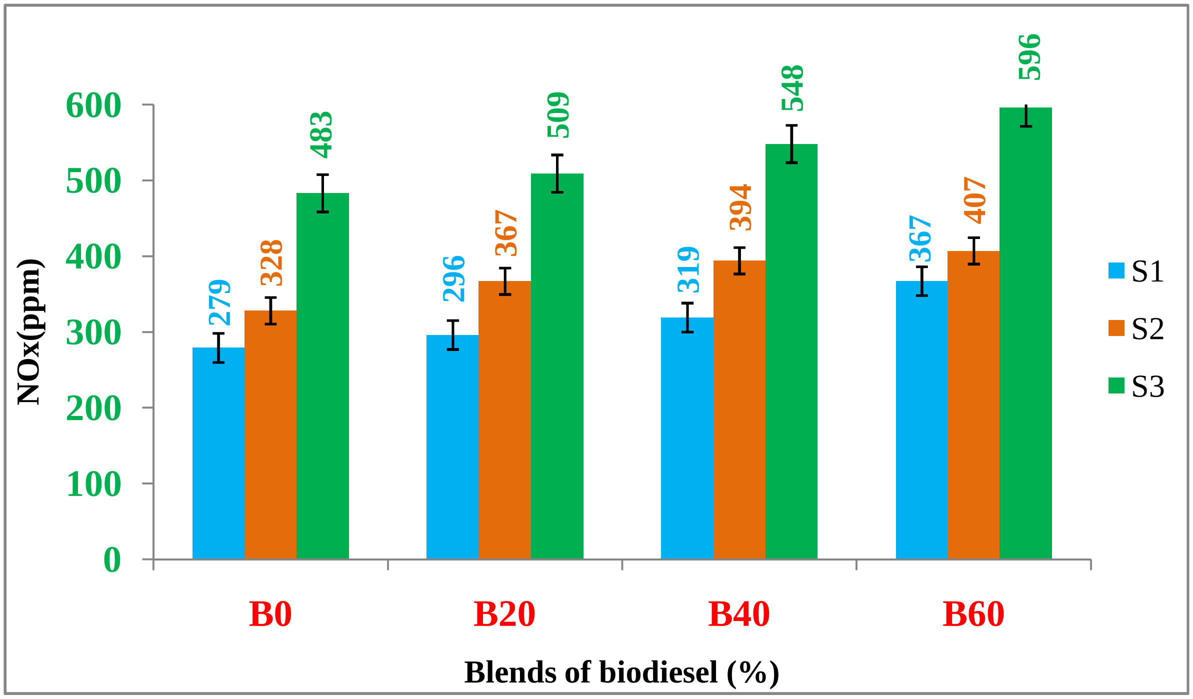


a. Ploughing operation

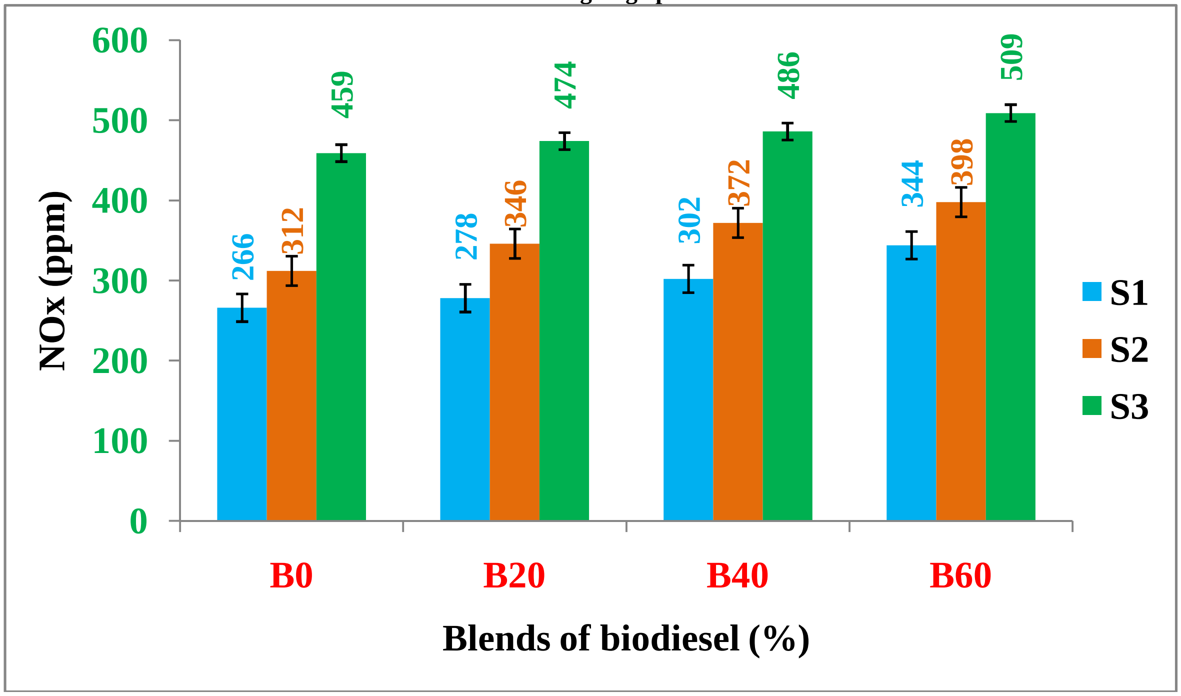


b. Harrowing operation

Fig. 1 Effect of forward speeds on CO emission for petro-diesel and selected blends of karanja biodiesel during tillage operations



a. Ploughing operation



b. Harrowing operation

Fig. 2 Effect of forward speeds on NO_x emission for petro-diesel and selected blends of karanja biodiesel during tillage operations