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AGRICULTURAL TRACTOR ENGINE PERFORMANCE AND EMISSIONS USING BIODIESEL-ETHANOL BLENDS

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KEYWORDS

biodiesel blend, ethanol blend, emission, performance, diesel engine.

ABSTRACT

To meet environmental standards and sustainability policies, diesel-biodiesel-ethanol blends have been investigated as partial replacements for diesel. This study aimed to evaluate the emissions and performance of a diesel engine using a blend of biodiesel and ethanol. Four blends of biodiesel (7, 10, 15, and 20%) and four blends of ethanol (0, 1, 3, and 5%) were used. The power remained stable with the addition of biodiesel but decreased with the addition of ethanol for all blends. The power was reduced from 76 to 74 kW when the ethanol content increased from 0 to 5%. The addition of 1% ethanol increased the maximum torque linearly from 372 to 378 kW. A slight increase in the specific consumption was observed with the use of biodiesel and ethanol in the blend. An increase in the ethanol fraction from 0 to 5% reduced nitrogen oxide emissions, especially at high loads. Ethanol caused a decrease of up to 42% in nitrogen oxide. At high loads, a reduction in carbon monoxide emissions was observed with an increase in the blends of ethanol and biodiesel. Blends of biodiesel and ethanol with concentrations of 20% biodiesel and 5% ethanol are alternatives to diesel in agricultural tractor engines.

INTRODUCTION

Increasing industrialization has increased the demand for fossil fuels, causing reserves of these fuels to drain at an alarming rate worldwide (Atmanli et al., 2015; Odibi et al., 2019; Yesilyurt et al., 2020). In addition, fossil fuels cause air pollution and global warming. Therefore, studies have aimed to develop new technologies that effectively use resources (Atmanli et al., 2016; Aydın, 2020; Uyumaz, 2020).

In this context, liquid biofuels produced from renewable biomass are attractive (Carneiro et al., 2017). Of these, biodiesel is the best option. Biodiesel is an oxygenated, renewable, biodegradable, and ecologically friendly fuel (Yilmaz et al., 2018; Gongora et al., 2022). It has properties similar to those of mineral diesel, with some advantages over diesel, such as a higher amount of cetane, the presence of oxygen that helps in combustion, and the reduction of greenhouse gas emissions (Guedes et al., 2018).

Biodiesel is a promising alternative fuel for diesel engines; however, its high viscosity, low volatility, and poor cold flow properties at low temperatures affect its combustion quality, which limits its emissions. High viscosity and low volatility affect fuel atomization, whereas poor cold flow properties lead to the solidification of fatty acid compounds and the formation of crystals at low temperatures (Bhale et al., 2009; Wei et al., 2018). However, fuel properties can be improved by blending biodiesel with ethanol. As a renewable alternative fuel with a high oxygen content, blending ethanol with biodiesel can decrease fuel density, viscosity, cold filter plugging point, and freezing (Jin et al., 2019; Atmanli & Yilmaz, 2020; Geng et al., 2021).

Researchers have investigated the effects of different proportions of diesel–biodiesel–ethanol ternary fuel blends on the performance and emission characteristics of diesel engines. Shahir et al. (2015) observed that the engine power and torque decreased with increasing ethanol proportion in a single-cylinder diesel engine. Tongroon et al. (2019) observed that NO_x emissions increased with increasing ethanol proportions. Wei et al. (2018) observed that

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biodiesel-ethanol blends were more effective in reducing NO_x emissions. Yilmaz & Sanchez (2012) observed that biodiesel-ethanol reduced NO_x emissions while enhancing CO emissions at engine loads below 70%. Although much research has been conducted on biodiesel, diesel, and biodiesel, divergent results have been found in the literature for low and high concentrations of ethanol. Therefore, there is no clear and uniform conclusion regarding the effects of the ethanol addition ratio on NO_x emissions.

Based on the abovementioned literature reviews, several studies have been conducted on the blending properties of biodiesel and ethanol. However, few studies have evaluated these blends in agricultural tractor engines, and many have used single-cylinder engines. Therefore, the objective of this study was to evaluate the emissions and engine performance of an agricultural tractor fed with diesel-biodiesel-ethanol blends.

MATERIAL AND METHODS

The test was conducted at the Universidade Estadual do Oeste do Paraná (UNIOESTE) in Cascavel, Paraná, Brazil.

The tractor used was a Ford/New-Holland model 7630 with an auxiliary front-wheel drive (TDA; 4 × 2), manufactured in 1995 with 3196 h of use (Table 1). The tractor had a power socket with a single speed of 540 rpm, a splined shaft with six splines, and a diameter of 35 mm. The original tractor tank was disconnected from the injection system, and an external tank with a capacity of 20 L was used in the tests. In the engine, the tests used diesel type A S500 fuel, pure biodiesel, and anhydrous ethanol (99,6% purity). Biodiesel is produced via the methyl route and is composed of soybean oil (68%), bovine fat (25%), pork fat (5%), and poultry oil (2%).

TABLE 1. Tractor specifications.

Item	
Mark	New Holland
Aspiration	Turbo
Power (NBR 5484)	75.8 kW a 2.200 rpm
Torque	407 Nm a 1.400 rpm
Torque reserve	23%
Number of cylinders	4
Cylinder	4.983 cm³
Injection type	Rotary pump
Compression ratio	17.5:1

A heat pump calorimeter model E2K with values provided in MJ kg^{-1} enabled the determination of the gross heating value of the fuels. This method has been described by Volpato et al. (2009). A pycnometer and four-decimal precision balance (Marte, model Ay220) were used to obtain the density at 20 ºC. These values were within the limit of 850–900 kg m^{-3}, as required by the National Agency of Petroleum, Natural Gas, and Biofuels (ANP, 2008).

The proposed diesel-biodiesel proportions (7, 10, 15, and 20%) were evaluated without ethanol (E0) and in the proportions of 1, 3, and 5% of anhydrous ethanol. It is suggested in the literature that up to 20% biodiesel (B20) is the most acceptable blend ratio in alternative fuel blends (Atmanli et al., 2016; Yilmaz et al., 2022).

For the torque and power measurements, a mobile dynamometer from the Eggers brand, model PT - 170 SE (KL-Maschinenbau GmbH & Co.), was attached to the tractor power socket, whose principle of operation is a magnetic brake by eddy currents (currents of *Foucault*). For the control and configuration of the dynamometer, this study used the software Eggers *PowerControl*® v2.1, produced by the same company that built the dynamometer. The equipment was manufactured in Germany and presented data following the DIN standard (*Deutsches Institut für Normung* or German Institute for Standardization) number 70020.

For the *PowerControl*® software to make the corrections of power values considering the test conditions, a Thermo-hygro-barometer, brand GREISINGER, model GFTB-100, was used to measure atmospheric pressure, relative humidity, and room temperature. It was also necessary to acquire the real rotation values before each dynamometric test. According to Farias, there may be errors in the rotation values shown on the agricultural tractor displays. A digital infrared tachometer (Peaktech, Model 2790) was used.

Specific consumption was determined using the method described by Heywood (1988). The thermal efficiency was determined according to Heywood (1988), based on the specific consumption and LCV.

Gas emission measurements were performed by applying four levels of manual loads through a dynamometer [25, 50, 75, and 100% of the maximum torque, corresponding to C1, C2, C3, and C4, respectively, and no charge (slow speed)]. NO_x and CO emissions were determined using a combustion analyzer from Bacharach (model PCA3-285). At each point, the measurements were performed for three minutes.

The experiment was set up in a 4 × 4 factorial scheme with four blends of biodiesel (7, 10, 15 e, and 20%) and four blends of ethanol (0, 1, 3, and 5%). In the engine performance experiments, an analysis of variance (ANOVA), Tukey's test with a 5% probability of error, and regression analysis were performed. In relation to the engine pollutant gas emissions, measurements were made only once at the end of the performance tests for each fuel evaluated.

RESULTS AND DISCUSSION

The heating value of the blends decreased with an increase in biodiesel and ethanol. A decrease of 2.56% in the lower heating value was observed when the ethanol content increased from 0 to 5%. The biodiesel blends showed a decrease (1.98%) when the biodiesel content increased from 7 to 20% (Fig. 1A).

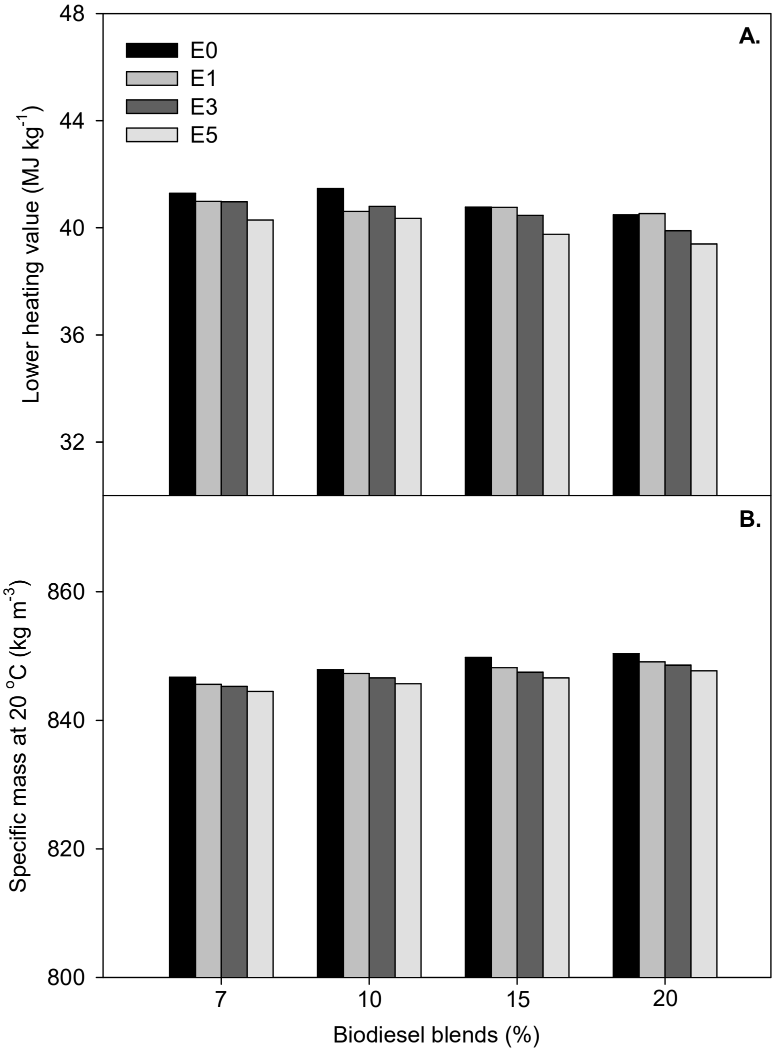

FIGURE 1. Lower heating value and specific mass of biodiesel and ethanol blends.

The biodiesel blends increased the specific mass of the blend, whereas an increase in ethanol content had the opposite effect, decreasing the specific mass. The highest specific mass value was found for the mixture with the highest percentage of biodiesel and no ethanol (B20E0) at 850 kg m^{-3} and the lowest with less biodiesel and more ethanol (B7E5) at 844 kg m^{-3} (Fig. 1B).

An increase in ethanol concentration caused a linear reduction in power. On average, the increase in the ethanol content in the blend reduced the power from 76 kW to 74 kW when the ethanol content was increased from 0 to 5% (Fig. 2A and B). Higher values of maximum power rotation were observed for the B7E3 and B10E3 blends. The blend containing 20% biodiesel and 5% ethanol caused a linear reduction in the maximum power rotation (Fig. 2C and D).

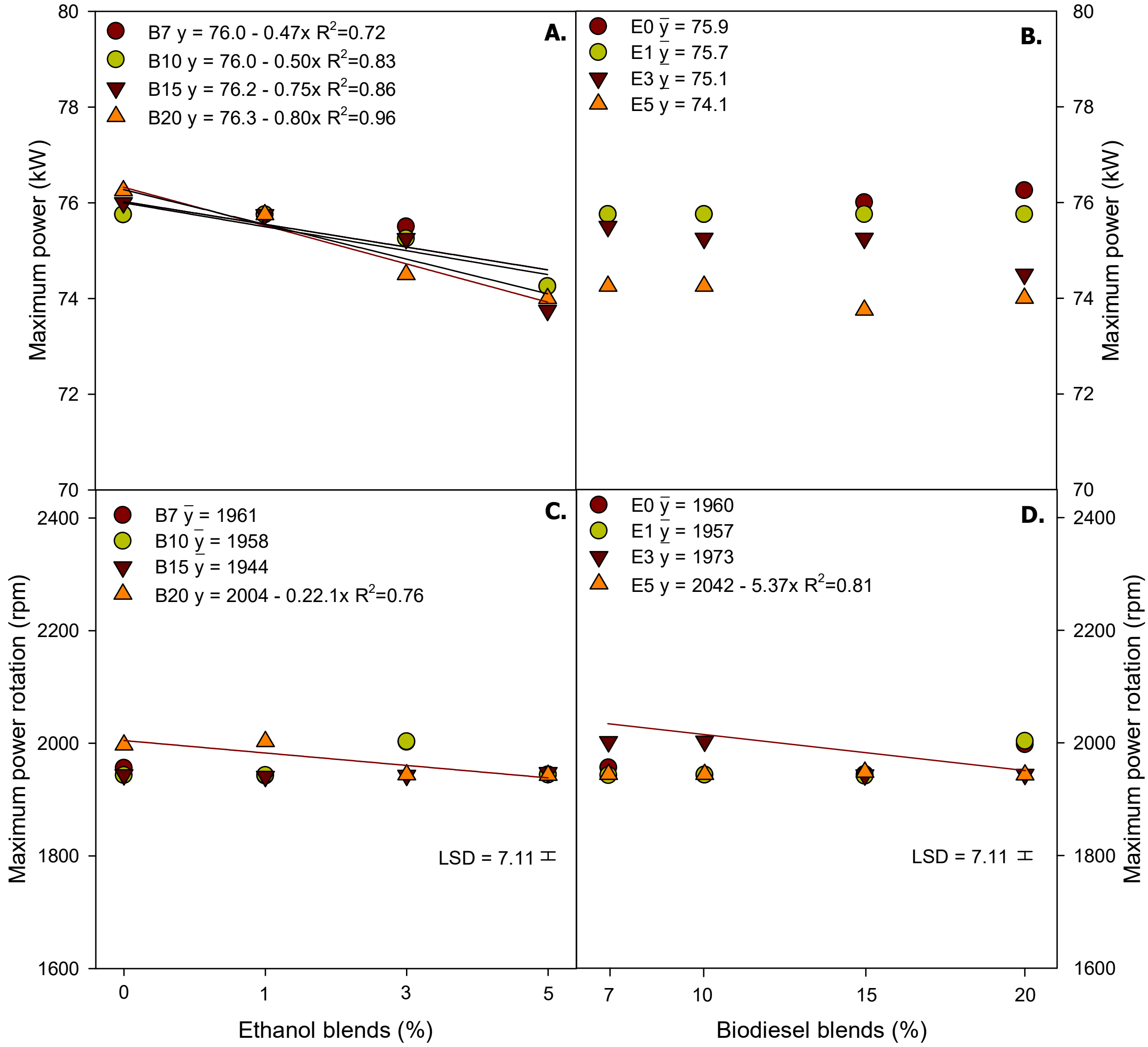

FIGURE 2. Regression analysis for maximum power (A and B) and maximum power rotation (C and D) of biodiesel and ethanol blends.

A linear decrease in the maximum torque was observed with an increase in ethanol fraction (1, 3, and 5%). The torque values were lower when 5% ethanol was added to the blend, regardless of the biodiesel blend (Fig. 3A and B). Except for the blend containing 1% ethanol, the biodiesel fractions (7, 10, 15, and 20%) exhibited regular torque behavior in the blends with 0, 3, and 5% ethanol. The addition of 1% ethanol linearly increased the maximum torque from 372 kW to 378 kW with an increase in biodiesel from 7 to 20% (Fig. 3A and B).

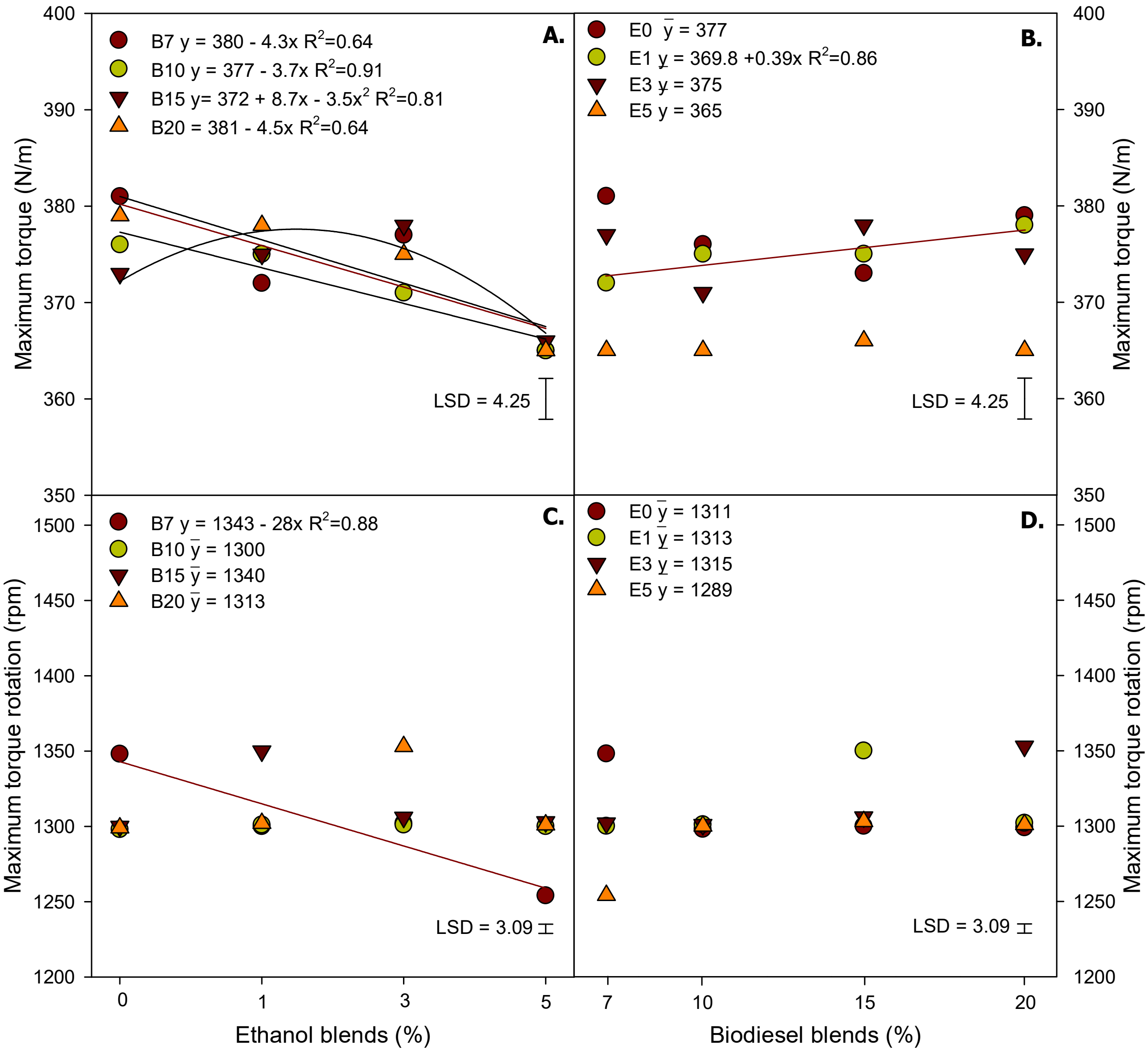

FIGURE 3. Regression analysis for maximum torque (A and B) and maximum torque rotation (C and D) of biodiesel and ethanol blends.

The maximum torque rotation covered three levels: 1250, 1300, and 1350 rpm. In general, the maximum torque was measured at a rotation speed of 1300 rpm. The increase in ethanol from 1 to 5% in the blend with 7% biodiesel caused a more evident linear reduction in the maximum torque rotation (Fig. 3A and B).

The increase in biodiesel and ethanol resulted in an evident increase in specific consumption (Fig. 4A and B). Higher specific consumption was observed for the blend B10E3 with 239 g kW^{-1} h^{-1} (Fig. 4A). When the ethanol content was increased from 1 to 5%, a slight increase in thermal efficiency was observed from 38.67 to 39.58%. There was little variation in the biodiesel blends, with values between 38.09 to 38.98% (Fig. 4A and B).

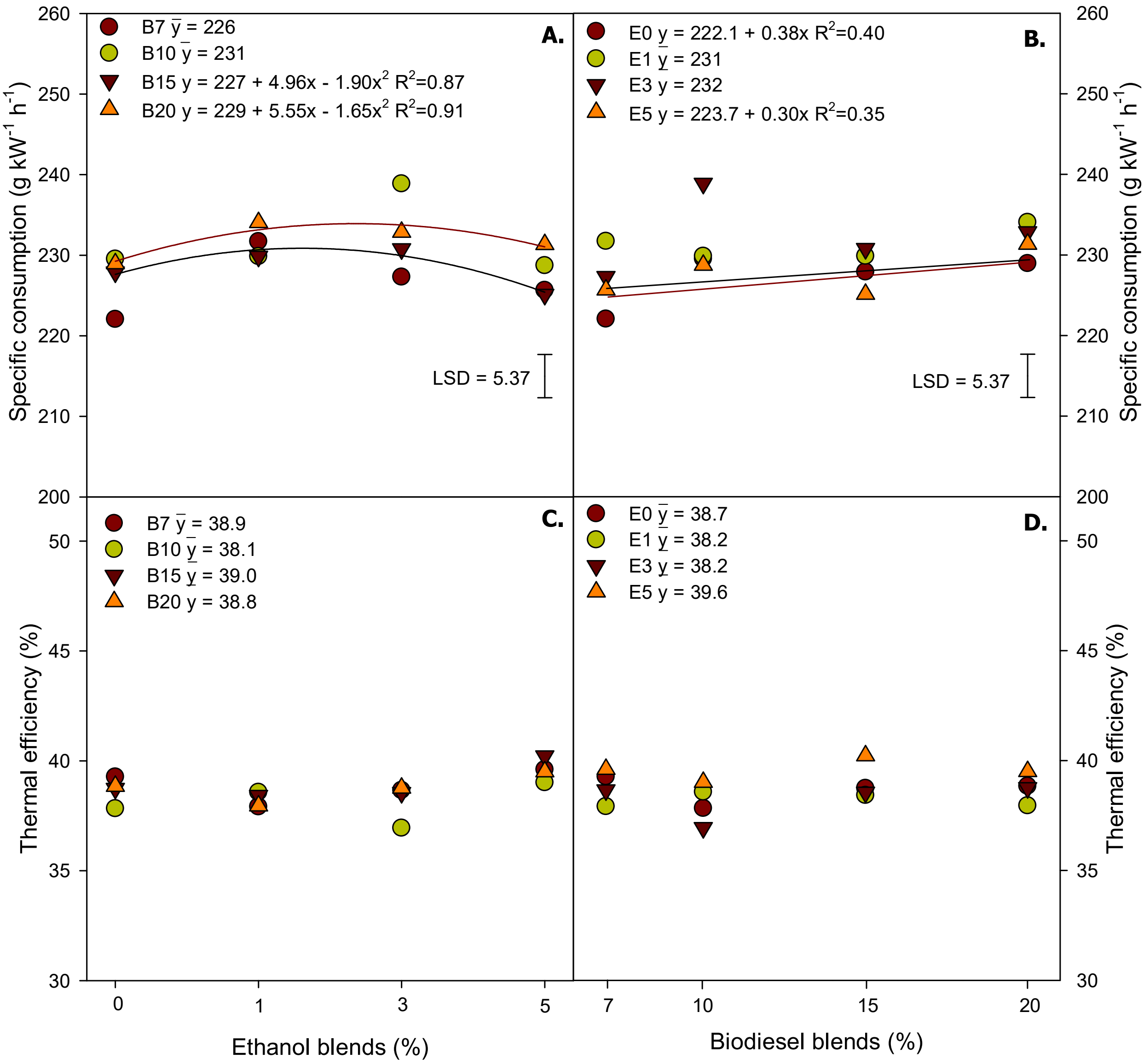

FIGURE 4. Regression analysis for specific consummation (A and B) and thermal efficiency (C and D) of biodiesel and ethanol blends.

The increase in ethanol fraction from 0 to 5% decreased the NOx emissions, especially for loads C1, C2, and C3 (Fig. 5A, C, and E). In load C4 and without load, a smaller effect of ethanol was observed, particularly with the addition of 7% biodiesel (Fig. 5I). Evidently, biodiesel tends to increase NOx emissions. In the C2, C2, and C4 loads, there was a tendency for a slight increase in the NOx emissions with an increase in the biodiesel blends (Figs. 5D, F, and H). However, at a high load (C1), an increase in the biodiesel blends did not cause an increase in NOx (Fig. 5B). At the idling speed, the NOx variations due to the blends of biodiesel and ethanol were substantially smaller (Fig. 5I and J). A linear reduction in NOx emissions was verified with the reduction in loads from 952 ppm in load C1 to 305 ppm to 114 ppm in load C4 (Fig. 5).

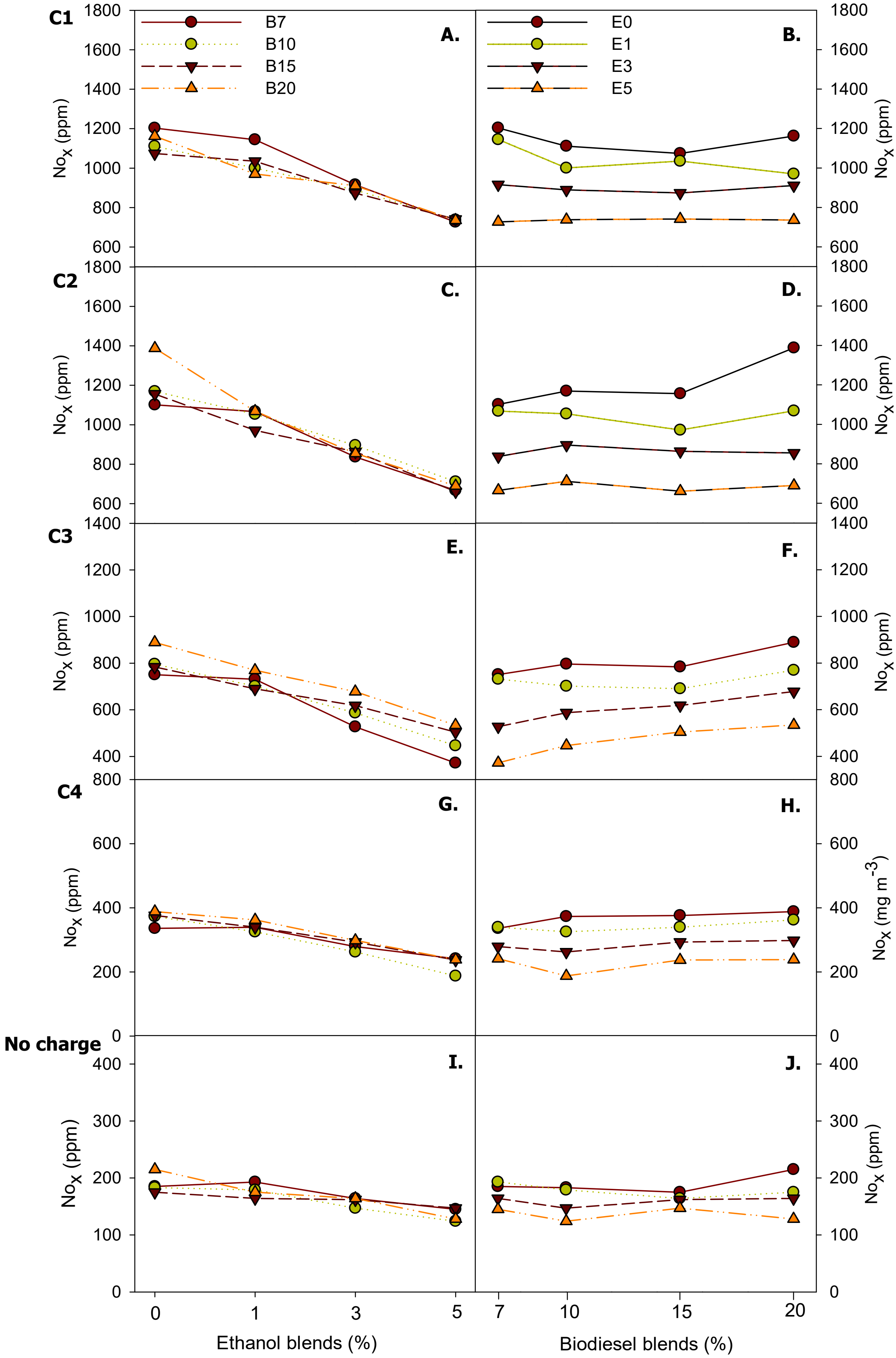

FIGURE 5. NO_x emissions in biodiesel and ethanol blends at different engine loads (A-J).

In load C1, a reduction in CO emissions was observed with an increase in the blends of ethanol and biodiesel. A reduction of 43.47% from 2678 to 1514 ppm was observed when the blend was changed from B0E0 to B10E5 (Fig. 6A and B). On average, for all loads, there was a slight reduction in CO because of the increase in biodiesel and ethanol. There was a linear reduction in CO emissions with a reduction in load, from 1969 ppm in the C1 load to 114 ppm in the C4 load (Fig. 6).

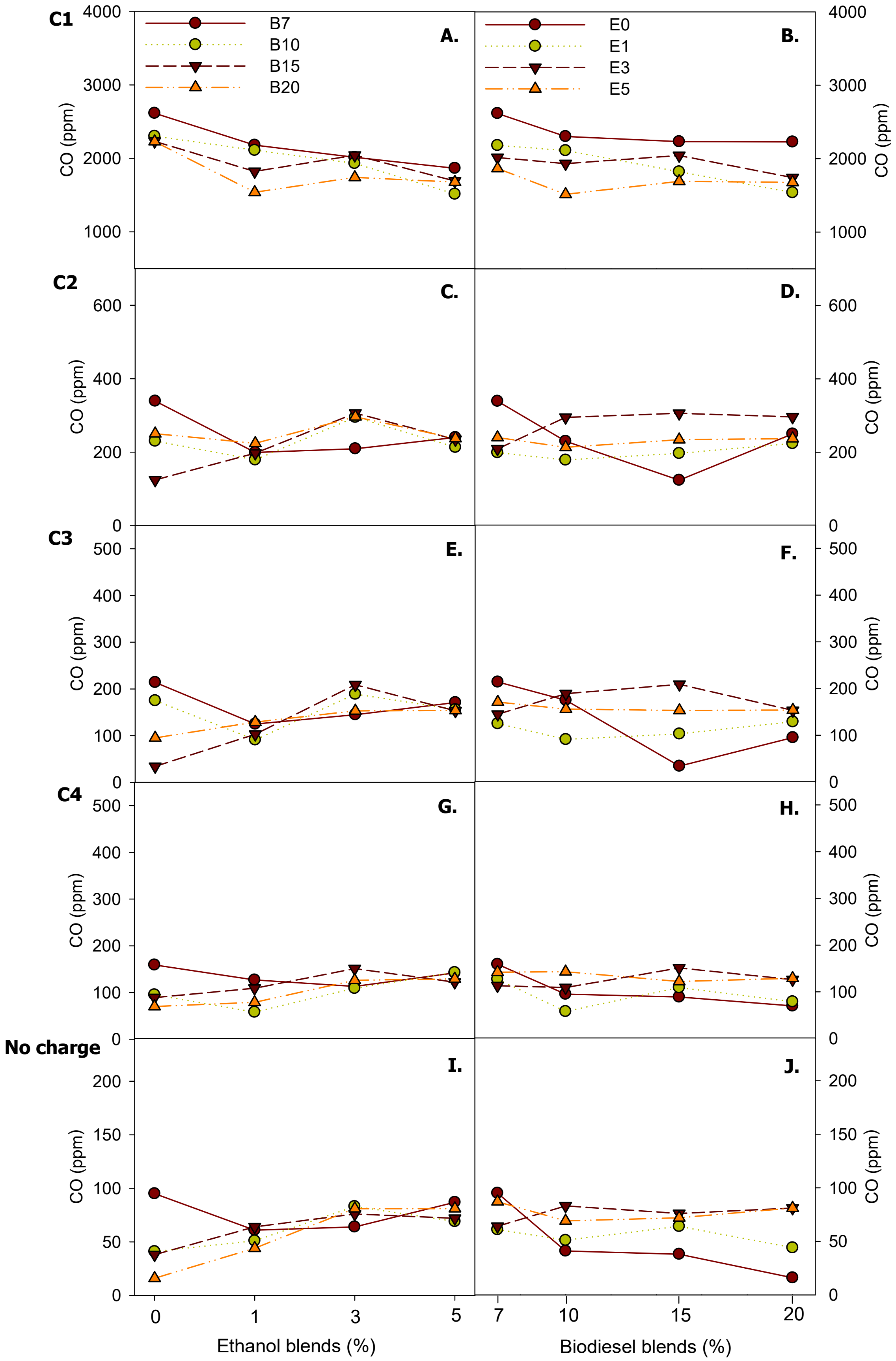

FIGURE 6. CO emissions in biodiesel and ethanol blends at different engine loads (A-J).

The power and torque decreased as the proportion of oxygenated compounds (biodiesel and ethanol/bioethanol) in the blend increased. This is possibly due to the low cetane number, calorific value, and higher ignition delay of the blends compared to those of diesel fuel (Xue et al., 2011; Shahir et al., 2015). Cheenkachorn & Fungtammasan (2009) observed an 8.7% reduction in power output using biodiesel and ethanol blends compared with diesel. Therefore, using these blends without additives reduces engine power and torque output (Shahir et al., 2015).

In general, the results indicated that increasing the proportions of ethanol and biodiesel in the fuel blend increased the specific consumption. This was expected owing to the reduction in the energy content of the fuel (Klajn et al., 2020). This behavior is attributed to the heating value per unit mass of ethanol, which is noticeably lower than that of diesel. Therefore, the amount of fuel introduced into the engine cylinder to achieve the desired fuel-energy input must be greater for ethanol. These results agree with those reported previously (Shahir et al., 2015; Thiyagarajan et al., 2020; Yesilyurt et al., 2020). Furthermore, high-specific-mass biodiesels generate less power when higher loads are required. High-density values indicate a higher viscosity, which can lead to greater flow difficulties and lower fuel injection (Kwanchareon et al., 2007).

The increase in specific consumption can also be explained by the lower heat values of biodiesel and ethanol compared to those of diesel. To compensate for the lower heat values of biodiesel, ethanol, and methanol, additional fuel must be injected to obtain the same power output. Ethanol has a lower stoichiometric air/fuel ratio than biodiesel and diesel fuels; therefore, blending alcohols into biodiesel leads to leaner combustion (Zhu et al., 2010).

Several authors have studied binary diesel-biodiesel blends in unmodified engines and reported that NO_x emissions increased with the use of esters, which is one of the major problems regarding the use of this biofuel in diesel engines (Masera & Hossain 2023). Randazzo & Sodré (2011) observed a similar behavior, where NO_x emissions increased with the use of biodiesel; however, this increase was reduced with the addition of ethanol to the blends, as observed in this study.

The decrease in NO_x emissions with high-load biodiesel may be due to the lower cylinder temperature, which in turn may be due to the lower heating value of the fuel (Abedin et al., 2014). The presence of a large number of oxygen molecules in biodiesel results in complete combustion of the fuel. This led to lower emissions of hydrocarbons (HC) and CO emissions. The temperature of the cylinder is an important factor in the formation of NO_x.

A reduction in CO emissions was observed with an increase in ethanol and biodiesel blends. CO emissions are directly linked to the air/fuel ratio because the richer the blend, the higher the percentage of CO produced. Because diesel engines operate on poor blends (more air and less fuel), a high amount of CO in the exhaust indicates excess fuel or a lack of oxygen in the blend. CO emissions are normally below the legal limit values, which is not a reason for special attention; therefore, an analysis of the CO level for poor blends (low loads) is useless. Kwanchareon et al. (2007) also evaluated ternary diesel-biodiesel-ethanol blends and claimed that the addition of oxygenated fuels to diesel resulted in a small effect on low and medium loads but significantly reduced CO emissions at high and full loads, as observed in this study. They pointed out that the impact of this blend on CO emissions varied according to the operating conditions of the engine and considered the results obtained inconclusively.

CONCLUSIONS

The power remained stable with the addition of biodiesel but decreased with the addition of ethanol for all blends. Higher values of maximum power rotation according to the interaction were observed for the blends B7E3 and B10E3. The increase in ethanol in the blend reduced the power from 76 kW to 74 kW when the ethanol content increased from 0 to 5%. A slight increase in the specific consumption was observed with the use of biodiesel and ethanol in the blend. An increase in the ethanol fraction from 0 to 5% reduced NO_x emissions, especially at high loads. Ethanol caused a decrease of up to 42% in NO_x. At a high load (C1), an increase in the biodiesel blends did not cause an increase in NO_x. At full load (C1), a reduction in CO emissions was observed with an increase in the blends of ethanol and biodiesel. Therefore, ternary diesel-biodiesel-ethanol blends reduced the emission of gases such as NO_x but reduced the power and torque of the agricultural tractor engine. Therefore, further investigations must be conducted using optimization methods and additives to make the adoption of ethanol in agricultural tractors commercially viable.

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