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PTO performance and NO_x emissions with D2, B20, and B100 fuels in a John Deere 3203 compact tractor

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ABSTRACT

Tests were conducted in fall 2006 on a John Deere 3203 diesel tractor to determine differences in specific fuel consumption, power take-off (PTO) torque, PTO power, thermal efficiency, and oxides of nitrogen (NO_x) emissions between No. 2 diesel (D2), 20% biodiesel (B20), and 100% biodiesel (B100). Four 1-hour tests were conducted on each fuel. The results indicated no statistically significant differences ($p \leq .05$) between D2 or B20 on any variable of interest. However, B100 resulted in significantly ($p \leq .05$) increased, specific fuel consumption and thermal efficiency and decreased PTO torque and PTO power over both D2 and B20. These data suggest that farmers could switch from D2 to B20 without any performance losses, but a switch to B100 would result in the use of more fuel and a loss of power and torque.

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MEET THE STUDENT-AUTHORS

Matthew K. Hardin

I came to the University of Arkansas from Conway, Ark., in 2003 to major in journalism. By spring 2004, I found a home in the agricultural communications program of the Agricultural Education, Communication and Technology program of the Bumpers College. I have been active on campus in the Agricultural Communicators of Tomorrow and as a resident assistant. I completed an internship with the Arkansas Farm Bureau in Little Rock in the area of communications technologies, during which I further developed my photographic skills. I graduated with a bachelor of science degree in agriculture in spring 2007.

Tonya Brown

I graduated from high school in Tecumseh, Okla., in 2002, having been very active in FFA and 4-H. I completed my bachelor of science in fall 2006 with a major in agricultural education, communication and technology. During my program I was a member of the livestock judging team and was active in Collegiate FFA/4-H. I served as president of the Collegiate Farm Bureau. I plan to teach agricultural sciences and technologies at the high-school level in Oklahoma or Arkansas.

Melanie R. Roller

I completed high school in Pea Ridge, Ark., in 2003, where I was very active in several student organizations, including the FFA. After coming to the University of Arkansas, I continued my participation in Collegiate FFA/4-H, serving in several officer roles. I was also an officer in the Collegiate Farm Bureau. I plan to graduate summer, 2007 with a bachelor of science in agriculture and a major in agricultural education, communication and technology. Beginning in fall 2007, I will be employed as an agricultural science teacher for the McDonald County Schools in Anderson, Mo.

INTRODUCTION

Given the recent rise in cost of petroleum-based fuels and the continuing U.S. dependency on them, the agricultural equipment industry is producing more tractors that can run on alternative fuels (Cousins, 2006). These fuels need to be studied to determine if they are viable alternatives to fossil fuels.

The National Biodiesel Board (NBB, 2007) defines biodiesel as a "fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751." The natural oil can be vegetable oils, cooking greases and oils, or animal fats (DOE, 2006). Most U.S. biodiesel is produced from the methyl ester of soybean oil, since this crop is available in sufficient quantities on a national level (Canakci and Van Gerpen, 2003).

Researchers (Proc, et al., 2006; Canakci and Van Gerpen, 2003; Schumacher et al., 2001) found little difference in power performance, specific fuel consumption, or thermal efficiency between engines fueled with No. 2 petroleum diesel (D2) or with blends of 80% D2 and 20% biofuel (B20). A study at Iowa State University found that biodiesel blends were similar to D2 in their thermal efficiency, but had higher fuel consumption (Monyem and Van Gerpen, 2000). Biodiesel was found to produce 15% and 16% lower exhaust carbon monoxide and hydrocarbons, respectively, than fossil fuels but there was no difference between the NO_x and smoke emissions of D2 and biodiesel (Monyem and Van Gerpen, 2000).

A University of West Virginia study used a 35% biodiesel blend on heavy-load engines. They found specific fuel consumption to be about the same as with D2 (Wang et al., 2000). Heavy trucks emitted lower particulate matter, carbon monoxide, and hydrocarbons than the same trucks fueled with D2 (Wang et al., 2000). Decreased power and increased specific fuel consumption have been found in engines fueled with B100, since it contains approximately 13% less energy than D2 (DOE, 2006).

One of the main arguments for the use of biodiesels is that they are better for the environment, but some researchers dispute this fact. Oxides of nitrogen (NO_x) are an EPA-regulated pollutant. Some researchers found increased NO_x emissions with biofueled engines (Canakci and Van Gerpen, 2003; Schumacher et al., 2001), while others (Proc et al., 2006) found no increase. Ongoing tests at the National Renewable Energy Laboratory show that "NO_x emissions do not always increase with B20 and in some cases actually decrease" (DOE, 2006).

The goal of this study was to determine if there were significant differences between PTO power, PTO-specific fuel consumption, PTO thermal efficiency, or PTO-specific NO_X emissions for a compact utility tractor fueled with D2, B20, or B100.

MATERIALS AND METHODS

Four one-hour steady-state tests were conducted using each fuel (D2, B20, and B100). PTO speed was maintained at a steady 540 rpm. PTO rpm, torque, power, mass fuel consumption, and NO_X emissions were measured at five-minute intervals. Ambient environmental conditions were monitored to ensure the tests were in compliance with the OECD Tractor Test Codes (OECD, 2006). The tests were conducted on a John Deere 3203 compact tractor with approximately 900 hours of prior machine use. It had a Yanmar three-cylinder diesel engine (Table 1) with gross engine power rated at 23.9kW (Compact Utility Tractor 3203 Operator's Manual, n.d.). The fuel system was drained and the oil filter was replaced prior to testing each fuel. An auxiliary fuel tank and an Ohaus SD-35 digital platform scale (35kg x 0.02kg) were used to measure the mass fuel consumption. An AW NEB 400 PTO dynamometer was used to apply the load and measure PTO performance (AW Dynamometer, Colfax, Ill.). The NO_x emissions were measured with an Auto Logic Gold 6-Gas exhaust analyzer (Auto Logic, Sussex, Wis.). The general characteristics of the fuels used are reported in Table 2.

RESULTS AND DISCUSSION

There was no significant difference in mean PTO speed by fuel type, with all mean speeds within 0.16% of the target speed (Table 3). There were no significant differences ($p \leq .05$) between D2 and B20 on any measure: PTO power, PTO torque, fuel consumption, NO_x emissions, or PTO rpm. When fueled with B100, the tractor produced significantly less PTO power and torque than when fueled with D2 or B20.

PTO-specific fuel consumption was significantly higher ($p \leq .05$) for B100 than for D2 or B20. However, PTO thermal efficiency was significantly ($p \leq .05$) higher for B100 than for D2 or B20. Finally, there was no significant difference ($p \leq .05$) in PTO-specific NO_x emissions between D2, B20, or B100.

The results related to power, torque, and specific fuel consumption support the findings of previous studies (Canakci and Van Gerpen, 2003; Schumacher et al., 2001). However, results related to thermal efficiency and NO_x emissions differ from previous studies. The lack of statistically significant differences in NO_x emissions across the three fuels, which are different results from previous studies, may result from differences between the testing methods used. Canakci and Von Gerpen (2003) tested under full-load conditions, while Schumacher et al. (2001) tested under transient-load conditions. Tests reported herein were conducted at rated PTO speed, which is a light load, but at high engine speed. NO_x emissions have been shown to increase with increased load and decreased engine speed (Li et al., 2006; DOE, 2006). The slightly higher thermal efficiency with B100 is likely due to load conditions and the energy content of the specific fuels used in this study.

These results confirm that tractors similar to this one may be fueled with either D2 or B20 with no significant differences in performance or specific fuel consumption. Fueling with B100 will result in increased PTO-specific fuel consumption, with a decrease in power and torque. When fueled with B100, the tractor PTO thermal efficiency was slightly higher than with D2 or B20.

Farmers can use these data to decide if they should switch to biodiesel or should continue to use D2. If the price of B20 is less than D2, and a farmer can use B20 without any performance losses, the conversion to B20 makes economic sense. However, the use of B100 would result in performance loses.

Further testing should be conducted to determine if there is a significant difference in NO_x emissions at increased load and decreased engine speed. Full-load testing would also allow for further evaluation of the higher PTO thermal efficiency found for B100.

In this study, the researchers did not consider the potential differences in engine wear, fuel system degradation, or cold-start issues associated with the use of biofuels. Consumers should take these factors into consideration, consult the manufacturers' warranty conditions, and follow the recommendations when selecting fuels.

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Table 1. John Deere 3203 specifications

Engine	Yanmar
Bore	84 mm
Stroke	90 mm
Displacement	1.5L
Gross engine power (rated)	23.9 kW
Compression ratio	19:01

[a]Compact Utility Tractor 3203 Operator's Manual

Table 2. Specific fuel characteristics

Property	D2	B20	B100
Carbon (% mass)	84.42[a]	85.10[a]	77.30[a]
Hydrogen (% mass)	13.38[a]	12.60[a]	11.80[a]
Specific gravity	0.814[a]	0.862[c]	0.886[a]
Kinematic viscosity, 40 oC (mm2/s)	N/A	2.92[a]	4.12[a]
Cetane number	46.1[a]	46.0[a]	47.5[a]
Heat of combustion, gross (BTU/lb)	19832[b]	19253[c]	16937[b]

[a]Values from DOE National Renewable Energy Laboratory Fuels Database.

[b]Analysis by Magellan Testing Laboratory (Kansas City, Kan.).

[c]Calculated value.

Table 3. Mean data for each output

	N		PTO RPM	PTO power (KW)	PTO torque (N-m)	Thermal efficiency (%)	SFC (kg/kW-h)	NOx emissions (g/kW-h)
D2	4	$\bar{x}$	540.15[a]	17.32[a]	306.48[a]	23.9[a]	0.327[a]	6.00[a]
		S.D.	0.0896	0.2880	5.6810	0.0040	0.0055	0.278
B20	4	$\bar{x}$	540.82[a]	17.19[a]	303.06[a]	24.4[a]	0.33[a]	6.23[a]
		S.D.	0.7500	0.0431	1.3843	0.0035	0.0047	0.073
B100	4	$\bar{x}$	540.25[a]	15.96[b]	282.25[b]	25.00[b]	0.366[b]	6.16[a]
		S.D.	0.1732	0.2358	4.7374	0.0065	0.0093	0.319
		F	1.14	48.19	36.45	5.44	40.17	0.087
		p	0.3617	< .0001	< 0.0001	0.0283	< 0.0001	0.4524

[a,b] Means with the same letters within columns are not significantly different.