Energy inputs for a combined tillage and liquid manure injection system

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McLaughlin, N.B., Grant, B.A., King, D.J. and Wall. G.J. 1997. **Energy inputs for a combined tillage and liquid manure injection system**. Can. Agric. Eng. 39:289-295. A combined tillage and liquid manure injection system was developed in an effort to curb contamination of subsurface drainage effluent following liquid manure application. The system is a modification of an existing liquid manure injection system and includes a coulter and cultivator tooth in front of each injector to provide a small amount of tillage prior to manure injection. Previous research showed a trend toward reduction in subsurface drainage effluent contamination with the new system, but the differences were not significant due to the high variability. This paper describes a field experiment to measure the draft and energy inputs for the modified injection system as compared to two different conventional injector designs and two surface spread systems. Results showed that the pretillage equipment on the modified injection system increased injector draft by 28 to 36% over that for the conventional injection system with narrow (50 mm) injectors. However, the draft of the modified injection system was only 66 to 77% of that for 570 mm wide conventional injectors. It was concluded that adding the tillage tools in front of the injector is practical from a draft and energy perspective.

Un système combiné de travail du sol et d'injection du lisier a été développé afin de réduire la contamination des effluents de drainage souterrain suite à l'application de fumier liquide. Le système est une modification d'un injecteur de fumier liquide. Un coutre et une dent de cultivateur placés devant chacun des injecteurs permettent de travailler le sol légèrement avant l'injection.Des recherches précédentes ont montré qu'un tel système semblait réduire la contamination des effluents de drainage souterrain, mais, à cause d'une trop grande variabilité, les différences n'étaient pas significatives. Cet article décrit une expérience au champ pour mesurer l'effort de traction et l'énergie requis pour le système modifié, et les comparer à ceux de deux modèles conventionnels d'injecteurs et deux épandeurs de surface. Les résultats montrent que l'équipement de travail du sol sur le système à injection modifié augmente l'effort de traction de 28 à 36% par rapport à un système conventionnel d'injection à injecteurs étroits (50 mm). Cependant, l'effort de traction du système à injection modifié n'était que 66 à 77% de celui d'un système conventionnel à injecteurs larges de 570 mm. On en a conclu que l'ajout d'équipements de travail du sol devant les injecteurs était intéressant du point de vue de l'effort de traction et de l'énergie.

INTRODUCTION

Surface spreading of liquid manure often results in significant odor and surface water pollution if runoff occurs shortly after application (Miller 1991). Injecting the manure below the soil surface can solve the problems of odor and surface water pollution from runoff. However, recent studies have shown that manure spread on the surface or injected below the surface on tiled land can reach the tile drains within 15 min after application resulting in surface water contamination via the drainage outlets (Fleming and Bradshaw 1992; King et al. 1994, 1996). The exact route by which the manure reaches the tile drains has not been investigated, but is believed to be via macro pores which may be a combination of soil cracks, worm holes, or channels left by decayed roots. It has been suggested that cultivating the field prior to liquid manure application can reduce the contamination of the tile drains (King et al. 1994, 1996). Although the mechanism by which the benefit is derived is not totally understood, it is thought that the pretillage disrupts macro pore continuity cutting off direct paths of liquid manure to subsurface drains.

Pretillage requires an additional field operation with additional labor, capital, and operating costs. Also, pretillage is not appropriate for no-till systems.

A prototype combined tillage and liquid manure injection system which provides minor cultivation in front of the injectors is presently under study as an alternative for use in reduced till, no till, and row crop systems (Hilborn et al. 1994; King et al. 1994, 1996). This new system will be referred to as "modified injection" throughout this paper. Pretillage is provided by coulters and narrow cultivator teeth mounted on tool bars in front of the injectors. The extra tillage tools for pretillage would undoubtedly create additional machine draft and require a larger tractor increasing both soil compaction and capital and energy costs. It is difficult to estimate the additional draft from published data on tillage machinery since the additional draft for the pretillage equipment would likely be partially offset by lower draft for the injectors operating in loosened soil.

The objectives of this paper were to compare draft and energy requirements of the modified injection system with two conventional injection and two surface spread systems. Drainage effluent contamination of the modified injection, conventional injection, and surface spread systems were reported by Hilborn et al. (1994) and King et al. (1994, 1996).

MATERIALS AND METHODS

A field experiment to measure draft of the modified injection system on a 7000 L Husky tanker, a conventional injection system on both the same Husky tanker and a 11,400 L Houle tanker, and surface spread on both the Husky and Houle tankers was conducted near Putnam, ON in August, 1993. A factorial experimental design was used with two speeds, five treatments or application systems, and five replicates. The same experiment was repeated on two fields with different soils and crop stubble conditions, alfalfa stubble on a Bennington loam soil and barley stubble on a Camilla sandy loam (Hagerty and Kingston 1992). The alfalfa and barley crops were harvested a few days before the experiment. The two fields will be denoted alfalfa and barley, respectively, to represent the stubble conditions. Factors in the experiment, liquid manure tanker specifications, and soil properties in the two fields are given in Tables I, II, and III, respectively. A sixth treatment consisting of the tractor only (no tanker) provided baseline fuel and axle torque data required to move the tractor without a load. The tractor only data were not included in the statistical analysis.

The Husky modified injection system consisted of a supporting frame with three tool bars mounted behind the tanker and fitted with a gauge wheel for depth control. The injector was mounted on the rear tool bar and consisted of a narrow 50 mm wide cultivator spike tooth followed by a flattened pipe which directed the manure slurry into the furrow opened by the cultivator tooth (Fig. 1). The front and middle tool bars were fitted with a 13 mm rippled coulter of 432 mm diameter and a 50 mm wide cultivator tooth, respectively, each set to run 50 mm on either side of the injector path and 50 mm deeper than the injector. Narrow teeth were selected for the injector and leading cultivator to minimize soil disturbance and subsequent crop damage when injecting between rows in a row crop (Hilborn et al. 1994). The leading coulter and cultivator tooth were removed to create the Husky conventional injection system. The Husky modified and conventional injection systems were the same units studied by Hilborn et al. (1994) and King et al. (1994, 1996).

The Houle conventional injection system consisted of a 510 mm diameter straight coulter followed by a 570 mm wide modified cultivator sweep. The spaces between the cultivator sweep wings and shank were covered with a metal plate welded to the wings. Manure was deposited under the sweep and allowed to exit beneath the raised rear section of the sweep. The Houle injectors had been altered from the original design supplied by the manufacturer, but for convenience the system will be referred to as the Houle conventional injection. The 50 mm wide Husky and the 570 mm wide Houle conventional injectors represented two extremes in injector width accepted by industry. Except for the leading coulter, pretillage equipment was not in-

Table I: Factors and levels in experimental design

Factor	No. of levels	Description
Soil and stubble	2	Bennington loam, Alfalfa stubble Camilla sandy loam, Barley stubble
Treatment or application method	5	Husky tanker, Surface spread Husky tanker, Conventional injection Husky tanker, Modified injection Houle tanker, Surface spread Houle tanker, Conventional injection
Speed	2	4.5 km/h 6.3 km/h
Replicates	5	

Table II: Liquid manure tanker specifications

	Tanker	
	Husky	Houle
Manufacturer	Husky Farm Equipment Ltd., Alma, ON	J. Houle & Fils, Inc., Drummondville, QC
Model	E	2650
Rated capacity	7,000 L	11,400 L
Axles	Tandem	Single
Tires	16.5Lx16.1 Implement	28Lx26 High flotation turf
Number of injectors	4	5
Injector spacing	750 mm	770 mm
Conventional injection configuration	50 mm wide cultivator chisel tooth	510 mm diameter straight coulter followed by 570 mm wide modified cultivator sweep[1]
Modified injection configuration	432 mm diameter, 13 mm rippled coulter plus 50 mm wide cultivator spike each offset 50 mm from injector, and 50 mm deeper than the injector	N/A
Pump PTO speed	540 rpm	1000 rpm

[1] Altered from original manufacturer's design.

Table III: Soil properties in the two fields

Property	Field	
	Alfalfa	Barley
Soil series	Bennington loam	Camilla sandy loam
Drainage	Well drained	Imperfectly drained
Topography	Gently rolling	Gently sloping
Range in slope[1]	-1.5 to +1.9%	-1.0 to 0%
Bulk density (Mg/m^3)	1.42	1.55
Soil texture		
Sand (%)	53.0	64.0
Silt (%)	31.1	24.8
Clay (%)	15.9	11.2
OM (%)	4.3	3.6
Gravimetric soil moisture content (%)	10.1 (2.1)[2]	11.9 (2.8)

[1] Slope sign is referenced to direction of travel; positive slope implies traveling up hill.

[2] Standard deviations are given in parenthesis.

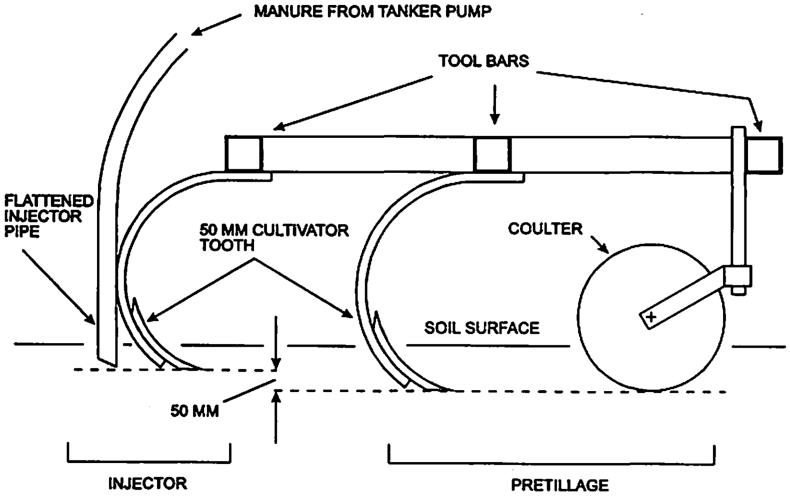

Fig. 1. Diagram of modified injection system mounted behind the Husky tanker. Depth gauge wheels and tanker are not shown. Conventional injection was created by removing the leading coulter and cultivator shank from the modified injection system.

stalled on the Houle tanker.

Twelve plots, 30 m long and 5 m wide (sufficient width to accommodate one pass of the tanker), were established in each of five blocks in each field. The mean slope for each plot was calculated from elevation measurements at each end of the plot obtained with a surveyor's level. Three soil samples were taken in the top 150 mm of each plot prior to the tests for gravimetric soil moisture determinations. Core samples were taken in transects in each field for bulk density and textural analysis. The soil parameters for the two fields are summarized in Table III.

Water was used in the tankers to simulate the tanker operating weight when applying liquid manure. The Husky tanker was operated full and the larger Houle tanker was operated partially full with the same volume of water as in the Husky. Thus the loaded weight was approximately the same for both tankers. The PTO pump on each tanker was operated during the tests, but the valves were shut off so that the water was not discharged thus maintaining a constant tanker weight. The valve in the Houle tanker diverted flow back into the tank while the valve in the Husky tanker simply closed off the outlet of the centrifugal pump. The PTO pump on the Husky was operated at 540 rpm while the Houle pump was operated at 1000 rpm as only the 1000 rpm PTO adapter shaft was available.

Draft and energy measurements were accomplished with Agriculture Canada's instrumented research tractor (McLaughlin et al. 1993). This tractor was fitted with a set of transducers and an on-board data logger to measure and record tractor operating parameters such as implement draft, axle torque, fuel consumption, and engine, wheel, and ground speed.

The tractor and tanker were brought up to speed in the buffer zone between the blocks of plots with the injectors either raised to simulate surface spreading, or lowered to simulate injection. A constant speed was maintained through the plot. Alignment of the row of stakes marking plots provided visual cues for manually starting and stopping the tractor data logger at the beginning and end of each plot. Signals from all transducers on the tractor were logged at a scan rate of 100 Hz and low pass filters for strain gage based transducers (forces in the hitch links, axle torques) were set at a 10 Hz corner frequency. The tankers were periodically unhitched from the tractor and "zero files" logged with no load on the tractor hitch.

Injector depth measurements were made by removing loose soil and measuring the depth of the injector furrow below a board laid on the undisturbed soil surface. Three depth measurements were made for each plot and a mean depth for each plot was calculated.

Mean values of each transducer signal were calculated for each plot from approximately 1700 and 2400 scans logged at nominal ground speeds of 6.3 and 4.5 km/h, respectively. Draft and axle torque data were corrected for the small instrument drift by subtracting the corresponding values from the most recent zero file obtained under no load conditions. The

Table IV: Mean operating depths for the liquid manure injectors in the alfalfa and barley fields

Tanker and injector configuration	Depth (mm)	
	Alfalfa	Barley
Husky -Conventional injection	92 (10)[1]	96 (7)
Husky - modified injection	108 (25)[2]	119 (6)
Houle - conventional injection	85 (8)	110 (26)

[1] Standard deviations are given in parenthesis.

[2] Depth for modified injection measured to bottom of furrow formed by leading cultivator tooth.

Table V: Analysis of variance table for drawbar draft

Source	DF	Mean square	F	Significance level
Alfalfa				
Treatment	4	655.38	355.43	0.0001
Rep	4	0.74	.40	NS
Speed	1	0.44	0.24	NS
Treatment*Speed	4	5.89	3.20	0.05
Error	36	1.84		
Barley				
Treatment	4	489.69	575.01	0.0001
Rep	4	0.88	1.03	NS
Speed	1	5.41	6.36	0.05
Treatment*Speed	4	5.12	6.01	0.01
Error	36	0.85		

corrected means were treated as dependent variables for the plots. Correction factors for plot slope were then determined by including plot slope as a covariate in the Analysis of Variance (ANOVA) carried out with the General Linear Models (GLM) procedure in SAS (SAS 1996). The appropriate slope correction factors were applied to drawbar draft, axle torque, and fuel consumption data prior to further analysis. Engine power was estimated from engine speed and the corrected fuel consumption using a regression model derived from previous PTO dynamometer tests. Axle power was calculated from axle speed and torque data and drawbar power was calculated from drawbar draft and true ground speed determined from the time required to traverse the 30 m plot length. Unfortunately, the PTO torque instrumentation malfunctioned and consequently, PTO power was estimated from the difference between estimated engine power and axle power; transmission losses were neglected in this calculation.

The corrected means of each plot for draft, fuel, and power were subjected to the Analysis of Variance using the General Linear Models (GLM) procedure in SAS (SAS 1996). Separate analyses were done on the draft data from the alfalfa and barley fields. Data on fuel consumption and estimated power from the alfalfa and barley fields were pooled and separate analyses were done on the two speeds, 4.5 and 6.3 km/h.

RESULTS AND DISCUSSION

Operating depth

The mean operating depth in the alfalfa field was slightly shallower than in the barley field, although the same machine settings were used in both fields (Table IV). Visual observations and soil moisture data (Table III) indicated that the soil in the alfalfa field was dryer and harder than in the barley field. The greater cohesion associated with the dryer fine textured soil likely contributed to the shallower operating depth in the alfalfa field. Also, any tire sinkage in the softer soil in the barley field would increase injector depth, particularly in the Houle tanker where the injector depth was referenced solely from the tanker frame. The Husky injector tool bar was operated in the "float" mode and injector depth was controlled by gauge wheels mounted on the tool bar.

Correction for plot slope

The correction factor for plot slope for the drawbar draft obtained from the analysis of covariance was 839 N per 1% slope. This was in good agreement with the theoretical value of about 1 kN per 1% slope required to pull a loaded tanker weighing approximately 100 kN up a frictionless ramp. Correction factors for axle torque were 901 and 488 Nm per 1% slope (applied to both rear axles) for the tractor and tanker and tractor only, respectively. Theoretical values were 843 and 451 Nm per 1% slope, respectively. The correction factor for fuel consumption was 0.567 and 0.342 L/h per 1% slope for the tractor and tanker and tractor only, respectively. The slope correction factors were applied to the data prior to calculation of the means given in Tables VI, VII, and VIII. These corrected means are, therefore, estimates of the respective parameters for a level field. Further analysis and calculations were performed on the slope corrected data and any discussion of data in the following sections of this paper refers to the respective data corrected for plot slope.

Drawbar draft

The Analysis of Variance for drawbar draft is given in Table V. Speed was significant (P=0.05) for the barley field but not the alfalfa field. As the difference in draft for the two speeds was small relative to the difference between fields, the draft data for the two speeds were pooled prior to calculation of the means for the different tanker and injector configurations (Table VI).

Draft for all injector configurations was higher in the alfalfa field than in the barley field (Table VI). The harder soil along with the structural support provided by the alfalfa roots would explain the higher draft in the alfalfa field. However, surface spread had higher draft in the barley stubble for the Husky, but not the Houle tanker. Draft for surface spread is the rolling resistance of the loaded tanker, which would be higher in the softer soil in the barley field due to greater tire sinkage.

Draft on a per injector basis was calculated by subtracting mean drawbar draft for surface spread from mean drawbar

Table VI: Mean draft for different tanker and injector configurations. Data from the two speeds were pooled

Tanker and injector configuration	Drawbar draft (kN)		Injector draft (kN/injector)	
	Alfalfa	Barley	Alfalfa	Barley
Husky - surface spread	2.8a[1]	3.7a	-	-
Husky - conventional injection	11.4b	11.0b	2.2 (1.4)[2]	1.8 (1.4)
Husky - modified injection	14.9c	12.9c	3.0 (1.5)	2.3 (1.4)
Houle - surface spread	2.8a	2.8d	-	-
Houle - conventional injection	22.4d	19.7e	3.9 (1.5)	3.5 (1.6)

[1] Means in the same column and followed by the same letter do not differ significantly (P=0.05) according to Duncan's Multiple Range Test.

[2] Standard deviations are given in parenthesis.

draft for injection and dividing by the number of injectors (Table VI). Standard deviation of injector draft was calculated from the sum of the variances of drawbar draft for surface spread and injection.

The draft for the Houle injector was substantially higher than the Husky injector in both fields (Table VI). This is expected since the Houle injector must cut a 570 mm wide slice, while the Husky injector only cuts a 50 mm wide slice. The draft data in Table VI are within the range reported in the literature. Laguë (1991) reported injector draft of 6.2 kN/injector for a 300 mm wide injector in alfalfa in a firm clay soil. Actual depth was not measured, but the injectors were limited to a maximum depth of 203 mm. Negi et al. (1978) reported injector draft for a 300 mm wide injector of about 3.0 and 7.0 kN for depths of 100 and 200 mm, respectively, in a clay loam soil. Hakimuddin et al. (1989) reported much lower drafts in the range of 0.4 to 0.7 kN for a 90 mm wide injector at 100 mm depth. Soil conditions were not given.

The draft for the Husky modified injection system was 0.8 and 0.5 kN/injector higher than the Husky conventional injection system in the alfalfa and barley fields, respectively (Table VI). The resulting draft of 3.0 and 2.3 kN/injector for the Husky modified injection system in the alfalfa and barley fields, respectively, was still less than that for the 570 mm wide Houle conventional injector (3.9 and 3.5 kN/injector for alfalfa and barley fields, respectively) and was about the same as the injector draft of 3.0 kN reported by Negi et al. (1978) for a 300 mm wide injector at 100 mm depth on a clay loam soil. These data indicate that although the modified injection system does have a higher draft than the conventional injection system on the Husky tanker, the modified injection draft is still within range of other injector designs accepted by the industry.

Fuel consumption

Fuel consumption data for the two fields were pooled and means were calculated on a per hectare basis using in-plot fuel consumption, plot length (30 m), and swath width (3.0 m for tractor only and the Husky tanker with four injectors spaced at 750 mm and of 3.85 m for the Houle tanker with five injectors spaced at 770 mm). The fuel consumption means are given in Table VII.

The difference between modified injection and conventional injection on the Husky tanker was only 0.6 and 0.4 L/ha at 4.5 and 6.3 km/h, respectively, or about 4% of the in-field fuel consumption. The extra fuel required for the modified injection system is inconsequential.

In all cases, fuel consumption was substantially higher for the lower ground speed. This was expected since the tractor was operated at the same engine speed and different gears were used to attain the two ground speeds. Thus the engine was under loaded at the low ground speeds and was operating at a lower fuel efficiency. For the tractor only treatment (tractor driven across the plot without the manure tanker), the only useful work done by the engine was to move the tractor and the fuel consumption was approximately two thirds of that for modified injection. Substantial fuel savings for the lower ground speed, or for surface spread which had a lower draft, could have been achieved by operating in a higher gear and at a lower engine speed (gear up, throttle down). However, sufficient engine speed must be maintained for proper operation

Table VII: Fuel consumption for different tanker and injector configurations

Application method	Fuel Consumption (L/ha)	
	4.5 km/h	6.3 km/h
Tractor only	9.0	5.9
Husky - surface spread	11.4a[1]	7.8f
Husky - conventional injection	12.9b	9.4g
Husky - modified injection	13.5c	9.8h
Houle - surface spread	16.3d	10.6i
Houle - conventional injection	20.1e	14.3j

[1] Means followed by the same letter are not significantly different (P=0.05) according to Duncan's Multiple Range Test. Tractor only data were not included in Duncan's Multiple Range Test.

Table VIII: Power distribution for different injector configurations on the Husky tanker. (Data from Houle tanker not included; data from alfalfa and barley fields pooled)

Injector configuration	Engine power (kW)	Axle power (kW)	Drawbar power (kW)	PTO power (kW)
4.5 km/h				
Surface spread	17.3a[1]	6.8a	4.3a	10.6ab
Conventional injection	26.2b	16.1b	13.2b	10.1ab
Modified injection	29.1c	18.1b	16.0c	11.0bc
Tractor only[2]	2.8	3.8	-	-
6.3 km/h				
Surface spread	20.7d	9.7c	5.6a	11.0bc
Conventional injection	34.6e	22.5d	20.5d	12.2c
Modified injection	38.9f	29.6e	26.3e	9.2a
Tractor only	3.5	5.2	-	-

[1] Means in the same column and followed by the same letter are not significantly different (P=0.05) according to Duncan's Multiple Range Test. Tractor only data were not included in Duncan's Multiple Range Test.

[2] See text for discussion of anomalies in power estimates.

of the PTO driven pump on the tanker to achieve the desired application rate.

The fuel consumption data in Table VII are based on a full tank; a slight decrease would be expected as the tanker is emptied. The data are in-field fuel consumption only and additional fuel for hauling from storage to the field and return would have to be added to the in-field fuel data for calculations of total fuel for liquid manure application. Also, the tractor was over powered for the tanker size for surface application and this tractor-implement mismatch would result in higher fuel consumption than for a proper match of tractor and implement size.

Fuel consumption was much higher for surface spread with the Houle tanker than surface spread with the Husky tanker even though the drawbar draft was nearly the same. This was attributed to the extra power required to operate the Houle PTO pump at 1000 rpm compared to 540 rpm for the Husky PTO pump. Also, the Husky centrifugal pump was operated at no flow (pump outlet closed by shut-off valve) while the Houle centrifugal pump was operated at full flow (flow diverted back into the tank) which would require more engine power and fuel.

Power

Estimates of engine, axle, drawbar, and PTO power for the Husky tanker and tractor only are given in Table VIII. Engine power is based on pooled fuel consumption data from the alfalfa and barley fields. The difference in engine power between the conventional injection and modified injection on the Husky tanker was 2.9 and 4.3 kW (significant at P=0.05) for nominal ground speeds of 4.5 and 6.3 km/h, respectively.

Axle power (axle torque times axle angular velocity) was greater than engine power for the tractor only configuration which is clearly impossible (Table VIII). This inconsistency is mainly due to the error in estimating engine power from fuel consumption and engine speed. One would expect PTO power to be the same for all application methods and both ground speeds while Table VIII shows significant differences. PTO power was estimated from the difference in engine power, which itself is only an estimate, and measured axle power; build up of errors resulted in the significant differences in estimated PTO power.

The power requirements in Table VIII are means for level land and do not include any reserve power for sloped land or tough spots. The data can be used for estimating differences in power requirements between application methods, but should not be used to size a tractor for a given application method. The tractor must have sufficient power, traction, and braking capability for safe operation of a heavy loaded liquid manure tanker, particularly on slopes or at elevated speeds such as on roadways. For example, a tractor with only 17.3 kW engine power with mass of less than two tonnes may have sufficient power for operation of the Husky tanker for surface spread at 4.5 km/h (Table VIII), but clearly would not have sufficient traction or braking capability for safe operation with a full tanker with mass of nearly ten tonnes.

SUMMARY AND CONCLUSIONS

A field experiment was conducted to measure draft, fuel consumption, and power requirements of a modified liquid manure injection system compared to surface spread and two conventional injection systems. The modified injection system included a coulter and 50 mm wide cultivator tooth to provide minor tillage in front of the injectors to impede the flow of the liquid manure to subsurface drains. Two field conditions, Bennington loam with alfalfa stubble and Camilla sandy loam with barley stubble, two nominal speeds, 4.5 km/h and 6.3 km/h, and two tankers, a 7000 L Husky and an 11,400 L Houle tanker were used in the experiment. The following conclusions were drawn:

1. Speed had a significant (P=0.05) effect on draft in the barley field, but not in the alfalfa field. The lower speed required approximately 30% more fuel on a per hectare basis due to the longer running time of the PTO driven tanker pump and the lower engine efficiency at lower engine loads.
2. Injector draft was from 11 to 30% higher on the alfalfa stubble than on the barley stubble, depending on the injector configuration. Soil moisture and visual observations indicated that soil in the alfalfa field was dryer and harder than in the barley field.
3. The 50 mm wide Husky injectors required 2.2 and 1.8 kN/injector at mean depths of 92 and 96 mm in the alfalfa and barley fields, respectively. Addition of the tillage tools (coulter and 50 mm wide cultivator chisel tooth) in the modified injection system increased draft by 36 and 28% to 3.0 and 2.3 kN/injector, respectively, for the alfalfa and barley stubble. In comparison, draft for the 570 mm wide Houle injector (no pretillage equipment) was 3.9 and 3.5 kN/injector for alfalfa and barley stubble, respectively.
4. The modified injection system increased engine power requirements by 2.9 kW (11.1%) and 4.3 kW (12.4%) (significant at P=0.05) for the 4.5 and 6.3 km/h nominal speeds, respectively, over that for the conventional injection system on the Husky tanker and increased in-field fuel consumption by 0.6 L/ha (4.6%) and 0.4 L/ha (4.2%) (significant at P=0.05) for the 4.5 and 6.3 km/h nominal speeds, respectively.
5. The data indicate that the modified injection system with the extra tillage tools requires higher draft, engine power, and fuel consumption than the conventional injection system, but that the differences are small enough for the modified injection system to be considered practical from an energy perspective.

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