Effects of Transmission Speed on Equipment Performance and Utilizing Spatial Equipment Performance Data for Management Decisions

C.M. Kichler[1], J.P. Fulton[2], R.L. Raper[1], W.C. Zech[3], T.P. McDonald[2], and E.B. Schwab[1]

[1]USDA-ARS-NSDL, National Soil Dynamics Laboratory, 411 South Donahue Drive, Auburn, AL 36832
[2]Auburn University, 200 Tom Corley Building, Auburn, AL 36849
[3]Auburn University, 283 Harbert Engineering Center, Auburn, AL 36849
Corresponding author email address: corey.kichler@ars.usda.gov

ABSTRACT

With fuel prices reaching all time highs, agricultural producers are searching for ways to minimize operational costs such as fuel usage while also increasing productivity. Adjustment of tractor operational variables including gear selection can optimize fuel usage and improve productivity during field operations. Further, spatial equipment performance data collected using global positioning systems (GPS) can also be utilized to make more informed management decisions regarding equipment and field performance. Therefore, the objectives of this investigation were to 1) investigate the effects of three transmission speeds on equipment performance for two subsoilers (Bigham Brothers Paratill™ and KMC Generation I Rip-Strip) and 2) demonstrate the possibilities of using spatial equipment performance data for management decisions. The data indicated that draft increased from the slow to fast speed by 27% (Paratill™) and 37% (KMC). Fuel consumption showed a 105% increase (slow to fast) for the Paratill™ and a 115% increase (slow to fast) for the KMC. The data from a spatial tillage experiment enabled a fuel cost map to be created to visualize fuel costs and formulate savings through site-specific management. In conclusion, adjustment of operational variables such as transmission speed as well as spatial analysis of equipment data can optimize performance and reduce input costs during tillage operations.

INTRODUCTION

Deep tillage operations are required to alleviate compaction layers often found in the Southeastern United States but this tillage can consume a significant amount of fuel and time for agricultural producers. Subsoilers are common implements used to break the compaction layer found in these soils. Tractor operational variables including transmission speed can be adjusted to increase productivity and decrease fuel usage if managed properly. In addition to machine operation methods, utilizing the GPS and geographic information systems (GIS) technologies to collect spatial data and perform analysis, respectively, can be insightful. Results can be used to develop site-specific management strategies or to modify equipment setup for future operations to improve efficiency and reduce costs.

Grisso et al. (2001) explained the “Gear Up and Throttle Down” concept for saving fuel. Adjusting to a higher gear enables the operator to run at the same travel speed and reduce engine speed 70% to 80% of the rated engine speed. They reported that a larger tractor pulling a light load using the geared up and throttled down concept will use the same or less fuel as a smaller tractor at full load. However, this operating technique is not applicable under increased loads such as those generated by deep tillage.

Ideally for conservation tillage systems, tillage should maintain minimum surface soil disruption while performing adequate subsurface soil disruption to alleviate hardpans. Implement shank design can have an effect on draft and overall equipment performance. Raper (2005) looked at force requirements and soil disruption of eight different subsoiler shanks (5 straight and 3 bentleg subsoiliers) on two different soil types. Results indicated that the straight shanks generated higher draft forces compared to the bentleg design for the Norfolk sandy loam soil (Raper, 2005). The bentleg shanks generated increased side force compared to the straight shank designs. Raper and Bergtold (2007) reported that the use of bentleg or inclined subsoiler shanks can save up to 15% in fuel and 32% in draft.

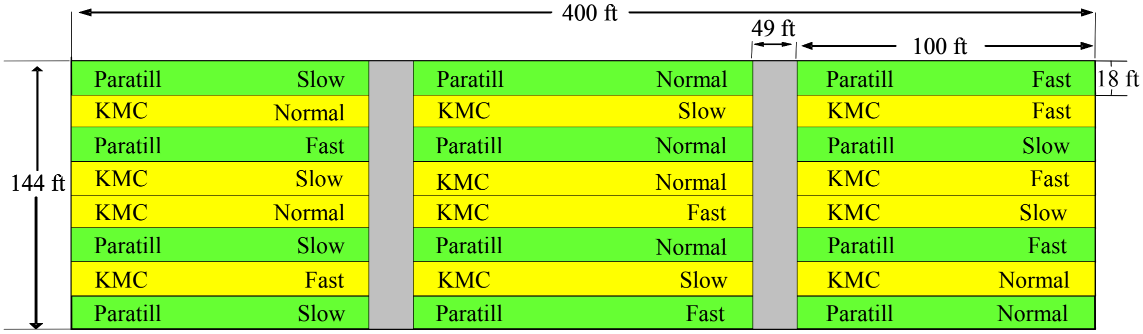
In-field performance monitoring can be important in understanding energy and fuel utilization. Yule et al. (1999) evaluated a real-time GPS data acquisition system on a Zetor agricultural tractor implemented with a tine cultivator outfitted with a consolidation roller. Variables monitored directly included fuel consumption, fuel temperature, engine speed, draft force, pitch and roll angles, GPS position, wheel speed, and ground speed. They created general performance maps of field slope, slip, and operating costs. Operating costs, excluding fuel costs, were calculated according to work rates collected with the tractor performance system. Areas of high slip were identified and field remediation was suggested so that operating costs could be minimized. They concluded that operating costs increased in areas of high slope causing increased wheel slip thereby reducing in-field equipment productivity.

Monitoring equipment performance during tillage operations can be beneficial in improving performance and the management of equipment. Therefore, the objectives of this investigation were to: 1) Investigate the effects of three transmission speeds (approx. 1.9, 3.6 and 5.2 mph) on equipment performance for two subsoilers, and 2) Demonstrate the possibilities of using spatial equipment performance data for management decisions.

METHODS

A 1.2 acre Cahaba sandy loam field located at the E.V. Smith Research and Extension Center in Shorter, AL was selected for this investigation. Three transmission speeds (slow, normal, and fast) with two deep tillage implements were used for a total of six treatments. The experimental design was a randomized block (Figure 1) with 4 replications and blocked based on the tillage implement. The plots measured 100-ft long by 18-ft wide. Each pass of the implement covered 3 plots with a 49.2-ft transition area between each plot. Gear changes occurred within this transition area without stopping or raising the implement out of the ground, allowing the equipment to reach steady-state prior to beginning the next plot. The desired tillage depth range for this experiment was 13 to 14 inches.

Two deep tillage implements were selected: a KMC Generation I Rip-Strip subsoiler and a Bigham Brothers Paratill™, both three-point hitch mounted with a six-row configuration. The KMC implement was a straight shank design while the Paratill™ was a bentleg design. Shank geometry for the Paratill™ and the KMC are presented in Figure 2. A mechanical front wheel drive (MFWD) John Deere 8300 agricultural tractor equipped with a Real-Time Kinematic (RTK) Trimble AutoPilot guidance system was used for this study. The autoguidance system ensured that the tractor maintained a straight path over the center of each pass. A 3-point hitch draft dynamometer fabricated by the USDA-ARS-NSDL in Auburn, AL was used to collect draft forces during tillage. An on-board data acquisition system collected engine speed, fuel consumption, axle torque, wheel speed, ground speed, and exhaust gas temperature (EGT) in real-time.



Paratill	Slow	Paratill	Normal	Paratill	Fast
KMC	Normal	KMC	Slow	KMC	Fast
Paratill	Fast	Paratill	Normal	Paratill	Slow
KMC	Slow	KMC	Normal	KMC	Fast
KMC	Normal	KMC	Fast	KMC	Slow
Paratill	Slow	Paratill	Normal	Paratill	Fast
KMC	Fast	KMC	Slow	KMC	Normal
Paratill	Slow	Paratill	Fast	Paratill	Normal

Figure 1. Experimental layout with treatment assignment and plot dimensions.

(a) (b) (c) (d)

Figure 2. Tillage shank geometry: (a) Paratill™ side view, (b) Paratill™ front view, (c) KMC side view, and (d) KMC front view (Raper et al., 2005).

Additionally, a spatial tillage experiment was also performed using GPS to link equipment performance data to geographic positions. A John Deere 6420 and a 2-row KMC Generation I Rip-Strip subsoiler was used to till a 3.7 acre field of Marvyn loamy sand located at the E.V. Smith Research and Extension Center, Shorter, AL. Spatial performance data was used to analyze the performance of the equipment throughout the field for the purpose of making site-specific equipment management decisions. The field was divided into 3 zones according to elevation changes to illustrate performance differences in response to field attributes. Figure 3 depicts field elevation map with the test area outlined. Zone 1 experienced a drop in elevation from south to north direction of about 6 ft over 279 ft of length. Zone 2 was relatively level with no more than 3-ft of elevation change over the 820-ft length. Zone 3 did have some slight elevation differences within the zone. Further, each zone was analyzed according to direction of travel (North or South) within each zone and compared.

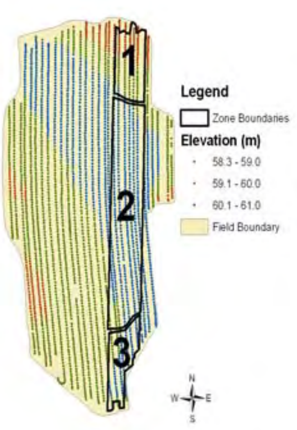


Figure 3. Spatial tillage experiment field elevation with zones outlined.

Results and Discussion

A summary of results for the transmission speed experiment are presented in Table 1. Equipment performance did respond to changes in transmission speed. Fuel consumption showed a 105% increase (slow to fast) for the Paratill™ and a 115% increase (slow to fast) for the KMC. Axle torque showed subtle increases throughout the speed ranges for the KMC. However, the Paratill™ demonstrated a slight decrease in axle torque from the slow to normal speeds by 1% illustrating that the implement pulled with less resistance at the normal speed. Power increased in response to speed with values reaching over 130Hp at the fast speed for both implements. Although not significant, fast speeds for both implements showed considerable increases in draft over the slower speeds shown with a 27% increase (Paratill™) and 37% increase (KMC) from the slow to fast speed. The Paratill™ had an interesting response to speed regarding draft with a 4% decrease from the slow to normal speed indicating an optimum performance range for this implement.

Table 1. Summary of performance data with statistical results for the Paratill™ (slow, normal, and fast) and KMC (slow, normal, and fast).

Implement	GS* (mph)	Slip* (%)	Engine* (rpm)	Fuel* (gal/h)	Torque* (ft-lbs)	Power* (Hp)	Draft* (lbs)	Vert* (lbs)
Paratill™	1.9^{a}	0^{c}	$2,275^{ab}$	5.0^{c}	$10,054^{ab}$	38^{b}	$7,673^{b}$	992^{b}
Paratill™	3.6^{b}	0^{c}	$2,264^{bc}$	7.0^{b}	$9,949^{bc}$	71^{c}	$7,356^{b}$	924^{b}
Paratill™	5.2^{c}	1^{bc}	$2,239^{d}$	10.2^{a}	$10,280^{a}$	135^{a}	$9,809^{a}$	$1,721^{a}$
KMC	1.8^{a}	1^{b}	$2,275^{a}$	4.7^{c}	$9,676^{c}$	36^{b}	$7,295^{b}$	-694^{c}
KMC	3.5^{d}	3^{a}	$2,260^{c}$	7.7^{b}	$10,267^{a}$	88^{d}	$9,123^{a}$	-372^{c}
KMC	5.0^{e}	4^{a}	$2,246^{d}$	10.1^{a}	$10,363^{a}$	138^{a}	$10,017^{a}$	-199^{c}

* Means with similar letters in columns are statistically similar ($\alpha = 0.05$)

The vertical force results showed increases at the fast speed over the slow speed for the Paratill™. The orientation of the draft dynamometer yielded positive forces as pulling the implement into the ground with a negative force pushing the implement out of the ground. The Paratill™ showed that as speed increased so did the vertical force indicating the implement pulled itself into the ground with a higher force as speed increased. This result was most likely due to shank geometry. The KMC tended to push itself out of the ground as indicated by the negative vertical forces. However, the magnitude of vertical force decreased with faster speeds signifying less force or energy was required to sustain the desired depth for the KMC.

The spatial tillage experiment showed that equipment performance was affected by field terrain. The results for comparisons of travel directions within each zone are presented in Table 2. Statistical differences were observed for fuel consumption (Fuel), engine speed (Engine), EGT, axle torque (Torque), wheel speed (Wheel), and ground speed (GS). No statistical differences were evident for slip. For zone 1, when tilling southbound the tractor had to tow uphill and northbound it was traveling downhill. According to the results (Table 2), zone 1 experienced a 23% increase in fuel consumption for the south direction compared to the north direction. A 17% increase in fuel consumption existed for the north direction of zone 3 compared to the south direction. No statistical differences were noticed between the north and south travel directions for zone 2. Zones 1 and 3 were located toward the ends of the test area meaning tillage would have initialized in the south direction of zone 1 and in the north direction of zone 3. Once the tractor begins tillage, it requires some time to get up to steady-state operation. During this time, the engine might notice increased loadings for a short period which would cause increased performance values for these directions. These effects can also be seen in the fuel cost map (Figure 4) illustrating increased fuel cost in orange and located primarily in zones 1 and 3.

Table 2. Summary of results by zone for the spatial tillage experiment.

Zone	**Direction****	**Fuel* (gal/h)**	**Engine* (rpm)**	**EGT* (°F)**	**Torque* (ft-lbs)**	**Wheel* (mph)**	**GS* (mph)**	**Slip* (%)**
1	N	3.5^{c}	2215^{b}	750^{bc}	2581^{c}	3.7^{e}	3.4^{b}	8.7^{a}
	S	4.3^{a}	2399^{a}	732^{c}	3427^{b}	4.0^{ab}	3.5^{a}	10.4^{a}
2	N	3.6^{b}	2190^{bc}	757^{b}	3611^{a}	3.6^{ce}	3.0^{bc}	9.5^{a}
	S	3.6^{bc}	2167^{cd}	766^{ab}	3009^{a}	3.6^{cd}	3.2^{bc}	9.6^{a}
3	N	4.3^{a}	2396^{a}	694^{d}	3081^{a}	4.0^{a}	3.6^{a}	9.8^{a}
	S	3.6^{b}	2142^{d}	779^{a}	3149^{a}	3.5^{d}	3.2^{c}	9.5^{a}

*Means with similar letters in columns were statistically similar ($\alpha = 0.05$).

** N and S represent North and South travel directions respectively.

The fuel cost map is comparative to a yield map, however instead of crop yield this map illustrates how the equipment is performing within the field regarding fuel usage. This enables managers to view areas of low performance and potential problem areas within the field and possibly create solutions to improve performance and reduce costs in these areas. For example, a wet area was present (Figure 4; indicated by arrow) in which the map showed higher fuel costs compared to other areas in the field. Potential uses for these types of maps include using them in conjunction with yield maps to possibly relate equipment performance and fuel cost to yield. This technology could also be used for fine-tuning site-specific tillage or other conservation tillage practices.

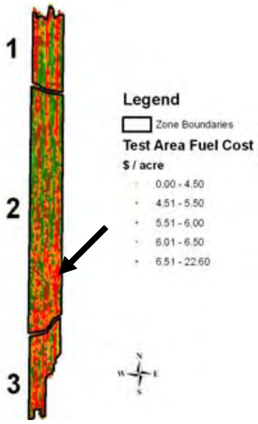


Figure 4. Fuel cost map for test area with zones outlined and arrow indicating wet area.

Conclusions

The results for these two experiments showed that performance was affected by equipment operational variables and field terrain. Increases in fuel consumption occurred as speed increased for both implements. The normal speed showed the lowest draft for the Paratill™. The fast speeds for both implements showed considerable increases in draft over the slower speeds with a 27% increase (Paratill™) and 37% increase (KMC) from the slow to fast speed. Each implement behaved differently in response to speed treatments. The reduced draft loads observed at normal speed for the Paratill™ indicate that an optimum performance range was found. Results also showed that implement and transmission gear selection could play an important role in equipment performance and decreased fuel usage. The ability to monitor and collect equipment performance data can benefit equipment management decisions and lead to fuel savings. Differences in performance were noticed between north and south travel directions which could possibly be improved with different tractor speed/gear configurations to optimize performance. The capability to collect and analyze spatial performance data enables managers to spatially plan tillage routes and perform field remediation in problem areas to improve efficiency in order to save on crop input costs incurred by tillage operation techniques. Combining adjustments including ballast, tire pressure, and gear selection can work together to further improve in-field performance during tillage operations and save costs for producers.

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