Measuring Machine Productivity with the MultiDat Datalogger: A Demonstration on Three Forest Machines

Chad T. Davis[1] and Loren D. Kellogg[2]

Abstract

Measuring productivity of forest equipment is an important aspect of managing costs in an industry consumed with operating for less. This study reports on an available option for monitoring equipment and the results and limitations a forest contractor could expect when using a datalogger to automatically gather production information. The MultiDat datalogger (engineered by FERIC) was installed on three different forest machines: 1) a Diamond 210 Cable Yarder, 2) a CAT 315C L excavator with a mulching head attachment, and 3) a CAT 518C rubber-tired grapple skidder. We observed 53:00:00 (53 hours), 75:30:00, and 7:34:00 for the three operations, respectively. Operator data entry errors impacted 1.6%, 17.1%, and 14.6% of observed time. However, operators described the datalogger as easy to use and expressed interest in knowing their results, suggesting that data entry errors may improve with comfort level. In summary, the MultiDat datalogger and software provides a good analysis tool at the contractor level for monitoring productive efficiencies and can aid in determining limiting aspects of the operation. It also seems to have applicability in long-term research studies where shift level information is part of a larger interest.

Key words: contractor, datalogger, efficiency, forest equipment, production

Introduction

Measuring productivity of forest equipment is an important aspect for an industry consumed with increasing efficiency and lowering operating costs. Most of this data is obtainable but usually the result of complex research projects that are cost prohibitive at the contractor level. Often knowledge only exists by contractor "seat of the pants" experience. The need for accurate information on machine productivity is imperative to improve project economics for forestry managers and forest contractors (Brown et al., 2002).

Additionally, most forest contractors have had to diversify their abilities to become more adept at operating on sites with different harvesting characteristics. In doing so, the need for information to quickly adjust aspects of their operation has, and will, become increasingly important to maintain economical stability. With the increased focus on lowering costs abounding in the industry, a forest contractor must have the ability to continually monitor operating procedures that significantly affect production efficiencies and costs.

Forest contractors must concern themselves with the footprint they leave on a

[1] Faculty Research Assistant, Forest Engineering Department, Oregon State University. chad.davis@oregonstate.edu. 541.737.9926

[2] Professor, Forest Engineering Department, Oregon State University. loren.kellogg@oregonstate.edu. 541.737.2836

harvest site. Certification efforts are beginning to require that contractors provide proof of environmental code compliance. Percent of area covered and soil disturbance, especially for ground-based machinery, are important criteria for public lands forest managers when considering harvesting options. Use of GPS technology for general tracking of machine travel has proven sufficiently accurate. (Veal et al., 2001)

The MultiDat[3], engineered by FERIC (Forest Engineering Research Institute of Canada), is a second-generation datalogger that monitors forest equipment and allows contractors to maximize machine uptime by recording and reporting activities and productive time (Brown et al., 2002). The datalogger also can be equipped with a GPS receiver to monitor machine movement and travel times. This information can be downloaded to create maps showing travel logs. This study exhibits to contractors the functionality of the MultiDat in regards to monitoring machine efficiency for harvest cost reduction and provides an example of its GPS capabilities.

Methods

The MultiDat datalogger utilizes an internal motion sensor and/or electric sensors to monitor machine motion and productivity. Only the motion sensor was used in these case studies. Use of the motion sensor required two inputs: a threshold value and a maximum time interval. The threshold value has no unit of measure and varies with each machine installation, depending on the amount of vertical and horizontal shake of the machine while idling. For each operation, the threshold value was configured to ignore a certain level of movement, ie. motor vibrations. As long as this minimum threshold value was met, the datalogger considered the machine to be in operation.

A maximum time interval was used to delineate operational delays from incidental pauses or datalogger sensitivity. In combination, non-productive time was recorded only when the MultiDat detected motion below the threshold value for a sustained period exceeding the maximum time interval. The datalogger would then prompt the operator to enter a stop code as to the reason for delay. The operator had a determined amount of time to respond before the datalogger recorded a No Response for the cause of delay.

The MultiDat was evaluated in three different case studies on different machines operating with different objectives: 1) Cable Yarder Study - a Diamond 210 Cable Yarder performing a commercial thinning, 2) Mastication Machine Study - a CAT 315C L excavator with a AFE[4] Rotary Mulcher head executing a non-commercial fuels reduction operation, and 3) Grapple Skidder Study - a CAT 518C rubber-tired grapple skidder performing a commercial fuels reduction harvest. Each required a unique datalogger installation due to the configuration of the machine and work being accomplished.

The motion sensor was utilized to detect productive time and delays associated with the Diamond 210 Cable Yarder. The wiring harness of the datalogger was wired to the master switch of the yarder, thus recording data anytime the master switch was to the on position. To ignore minor vibrations, the threshold value was set to 8 and

---

[3] The Multi-Dat is manufactured by GENEQ, Inc. For more information see http://www.geneq.com.
[4] Advanced Forest Equipment. For more information see http://www.advancedforest.com.

the maximum time interval was set to 2 ½ minutes. Delays not longer than 2 ½ minutes were considered part of the productive cycle. Stop code prompts lasted for 99 seconds (the maximum allowed time) and No Response was recorded if no stop code was entered. There were 10 codes that the operator had as explanation to the cause of delay (Table 1).

For the Mastication Machine Study, the datalogger was wired to the battery of the machine. The harness was connected and disconnected at the beginning and ending of each shift. The motion sensor was used to determine productive time as in the Cable Yarder Study. However, due to idling motion differences of the excavator versus the yarder, the threshold was set to a value of 6. A longer maximum time interval time of 5 minutes was used to remain consistent with another data capture portion of this machine for a different study. One of eight stop categories was used to describe the cause of each delay (Table 1).

Table 1—*Stop and Activity Codes Used for Each Portion of the Study*

		SKIDDER	
CABLE YARDER	**MASTICATOR**	**Delay**	**Activity**
Mechanical	Machine Mechanical	Wait Processor	Outhaul
Carriage	Head/Teeth Mechanical	Wait Skidder	Grapple
Line	Discuss-Research	Wait Other	Inhaul
Crew	Planning	Mechanical	Decking
Interference	Machine Maintenance	Maintenance	Cleaning
Choker Set	Head/Teeth Maintenance	Personal	Other
Landing	Personal	Discuss-Research	
Road Change	End Day	Discuss-Crew	
Personal		Other	
End Day		End Day	

A different data collection approach was used in the Grapple Skidder study than in either of the above two, attempting to mimic a detailed time study more typical of forest equipment research. Instead of utilizing the motion sensor, the operator manually input all data through the entry of both activity and stops codes. Activity codes were summed to yield productive time. Wiring was similar to the Mastication Machine, involving only the battery. There were 6 activity codes (skid cycle elements) and 10 delay codes used to record each step in the operation (Table 1). Because the datalogger did not stop the internal clock for activity codes when the operator entered a stop code, delay times had to be subtracted from each cycle element during analysis to yield a correct productive time.

Data from each operation was downloaded from the datalogger and initially analyzed using the MultiDat software. Reports were generated and exported to Microsoft Excel. To allow for greater flexibility in data analysis, secondary reports were generated from exported raw data using a macro. This custom program allowed the researcher to amend data resulting from datalogger setup (discussed below) or varying operator shift hours that was not easily maneuverable within the MultiDat software.

Results

Results are reported for the three applications separately due to the uniqueness of data collection for each: 1) Cable Yarder, 2) AFE Mastication and 3) Grapple Skidder. These results are not intended for production rate comparisons between machines but should indicate typical expected outcomes of data collected using the MultiDat for each system when using similar datalogger setups as this study. There exists some discussion in this section that relates to the explanation of the results.

Cable Yarder Study

The Cable Yarder Study occurred during a thinning of a Douglas-fir (*Pseudotsuga menzeseii*) second-growth stand in western Oregon. A standing skyline shotgun with a mechanical slackpulling carriage was the harvesting system in use and employed 6 crew members. Yarding distances ranged from 200 ft. to 1000 ft., averaging roughly 350 ft for the duration of this study.

After minor amendments within the data adjusting for the continuity of road change delays, total productivity for the cable yarder operation was 52.4% of the total observed 53 hours (53:00). Percentages of daily productive time ranged from a low of 42.8% to a high of 76.5% (Table 2).

Table 2. ***General Breakdown of Productive Time for Cable Yarder Study***

Date	Scheduled Time (hh:mm)	Productive Time	Road Change	Interference	No Response	End Day
18-Oct-04	09:00	76.5%	6.5%	13.0%	0.0%	3.1%
19-Oct-04	09:00	42.8%	42.6%	14.4%	0.0%	0.6%
20-Oct-04	09:00	46.7%	18.9%	25.9%	2.8%	6.1%
21-Oct-04	09:00	48.7%	33.7%	16.5%	0.0%	0.0%
22-Oct-04	08:00	50.6%	16.7%	19.8%	4.8%	0.6%
25-Oct-04	09:00	48.7%	44.4%	4.8%	2.2%	0.0%
Total	**53:00**	**52.4%**	**27.3%**	**15.7%**	**1.6%**	**1.8%**

After productive time, the remainder of scheduled time was broken down into four general categories. Road Changes accounted for 27.3% of scheduled time, Interference 15.7%, No Response 1.6% and End Day 1.8%.

Daily road change percentages ranged from 6.5% to 44.4% and Interference (mostly in reference to the processor/yarder interaction) ranged from 4.8% to 25.9%. The ranges for No Response and End Day were similar with both low end values at 0% and high end values around 5-6%.

Mastication Machine Study

The Mastication Machine study took place in a natural Ponderosa Pine (*Pinus ponderosa*) stand in central Oregon. This operation was part of a larger study conducting a non-commercial fuels reduction in which standing trees were being "thinned" to a residual spacing of 16 ft. Only trees less than 9" dbh (diameter at breast height) were considered for removal.

Results for the mastication machine are compiled from 8 days of operation totaling 75 hours and 30 minutes (75:30) of total observation (Table 3). Productive time was 65.1% of scheduled time. Start and end times for the mastication machine had to be manipulated after data export due to the randomness of operator hours.

Percentages of daily productivity ranged from 0.0% to 82.2%.

Table 3. ***General Breakdown of Productive Time for Masticator Study***

Date	Scheduled Time (hh:mm)	Productive Time	Equipment	People	No Response	End Day
28-Oct-04	6:00	68.1%	0.0%	5.6%	14.4%	11.9%
3-Nov-04	9:00	82.2%	0.0%	0.0%	0.0%	15.2%
4-Nov-04	10:30	67.3%	1.3%	8.1%	0.0%	23.5%
5-Nov-04	8:00	0.0%	100.0%	0.0%	0.0%	0.0%
8-Nov-04	11:00	74.1%	20.0%	2.1%	3.9%	0.0%
9-Nov-04	10:00	73.5%	0.0%	5.7%	21.0%	0.0%
11-Nov-04	11:00	69.8%	0.0%	4.5%	0.6%	25.2%
12-Nov-04	10:00	74.5%	0.0%	0.0%	20.8%	0.0%
Totals	**75:30**	**65.1%**	**13.7%**	**3.3%**	**7.4%**	**9.7%**

General delay categories were used at the most general level of analysis. The largest delay category was Equipment Delays, accounting for 13.7% of scheduled time. People delays accounted for 3.3% of scheduled time and ranged daily from 0.0% to 8.1%. No Response was recorded for 7.4% and ranged from 0.0% to 21.0%. Use of End Day was rather large, accounting for 9.7% of total time and ranging from 0.0% to 23.5%.

One interesting observation occurred on Nov. 5th when productive time was 00:00. This was an 8 hour shift in which an equipment delay was responsible for a total lost shift. The operator was off the job in search of a hydraulic hose for the machine. The short study period inflated the impact of this delay.

Grapple Skidder Study

The Grapple Skidder Study was also part of another fuels reduction project. Here, the intended goal was to reduce stocking levels in a mixed conifer stand in southern Oregon by commercial means. Stems of non-commercial size were bunched and skidded to the landing for biomass conversion. The ground-based harvesting operation employed 5 crew members – 2 skidder operators, 1 feller-buncher, 1 processor and 1 loader.

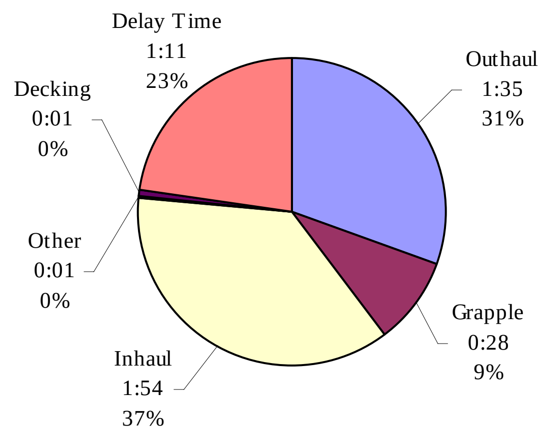
As stated earlier, the Grapple Skidder study relied on total operator input for each production and delay element of the skidding cycle. Some cycles were eliminated from analysis because of input errors. Reported results are the analysis for 11 hours, 48 minutes (11:48) of the 14 hour operation.

Cycle Element Analysis

One of the objectives in this study was to evaluate the automation of obtaining individual cycle time elements for skidding. This data is imperative for typical forest machine detailed time studies. If data could be obtained via the MultiDat successfully, study length could be extended for detailed time analysis of forest operations research. The Grapple Skidder Study evaluated gathering research quality cycle time element data with the datalogger. Forest contractors could also find this level of data useful when a detailed analysis is desired to adjust one facet of the operation for improved efficiency.

The average productive skid cycle time over 137 turns was 4 minutes (04:00), 77% of the average total skid cycle time of 05:11 (Figure 1). Inhaul (01:54) accounted for the most time of all skid cycle elements for the average turn. Outhaul (01:35) consumed the second most time, followed by Grapple (00:28), Decking (00:01) and Other (00:01). The low time for Decking was due to project definitions of cycle elements. The operator was only to record Decking if additional time was required to deck logs for the processor. Because the datalogger only recorded to the nearest minute, results reported to seconds are only the results of averaging.

Figure 1. ***Cycle Element Times for the Average Skid Cycle for the Grapple Skidder Study, n = 137 turns***
(time format is minutes:seconds)



Delay Analysis

All delays accounted for 22.7% of scheduled time (Table 4). Individual categories of delay exhibited small percentages of scheduled time ranging from 0.0% to 9.9%. Interference is a combined delay category from three stop codes in Table 1 above; Wait Processor, Wait Skidder and Wait Other. Lumped categories were used in this general analysis in response to the short study time. Discussion, also a lumped category, consumed the second most delay time at 6.2%, of which 4.2% was Discussion-Research. Equipment delays, 2.7%, had a relatively small affect on productive time. The use of End Day and Personal were almost negligible.

Table 4. ***General Breakdown of Productive Time for Grapple Skidder Study***

	12-Aug-04	13-Aug-04	TOTAL
Scheduled Time	7:34	4:14	11:48
% Productive	**79.9%**	**72.5%**	**77.3%**
Interference	9.6%	10.3%	9.9%
Discussion	4.2%	9.8%	6.2%
Equipment	2.2%	3.5%	2.7%
Other	3.1%	0.0%	2.0%
End of Day	0.9%	1.6%	1.1%
Personal	0.0%	2.4%	0.8%
Delay Total	**20.0%**	**27.6%**	**22.7%**

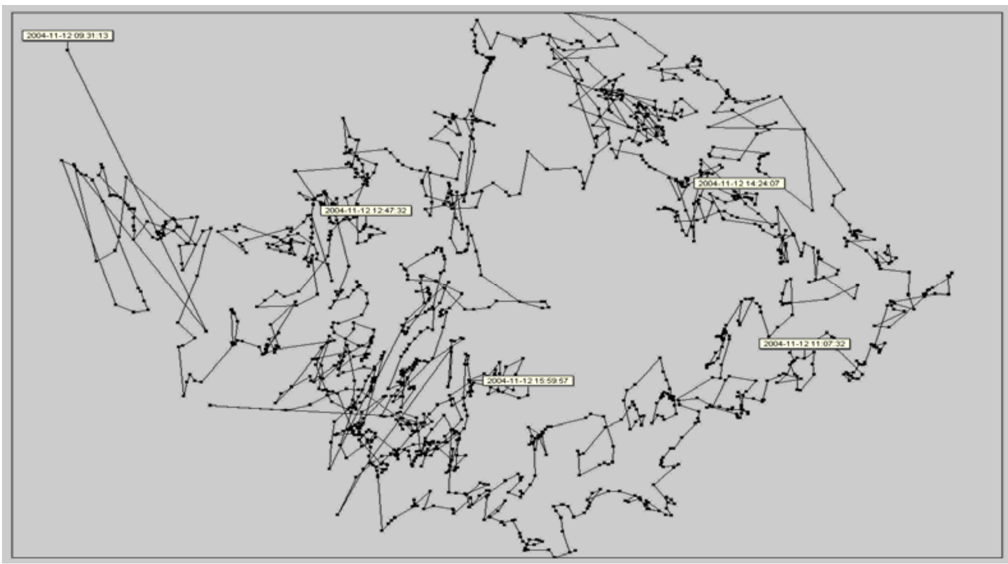
Delays contributed 01:11 to the average total skid cycle time (Figure 1). Delays occurred on 48.2% of observed cycles (66/137). Interference added 31 seconds

(00:31) to the average skid cycle time, followed by Discussion (00:19). Other, End Day, and Personal were responsible for little of the average skid cycle time and occurred infrequently.

Use of GPS

The GPS was installed and used for the Mastication Machine study and the Grapple Skidder study. Figure 2 is an example of the typical results provided by the MultiDat software. Data points were collected at 15 second intervals or when the machine had moved 100 meters. This data can be exported to mapping software packages and overlain on maps showing unit boundaries.

Figure 2. GPS track log for Mastication Machine on 11/12/2004.



Track logs generated in both case studies resulted in some apparently erroneous data. Although the general travel pattern and location of the track log was sufficient, individual data points were notably incorrect. Some points, taken at 15 second intervals, were farther apart by more than the twice the travel distance possible at maximum vehicle speed. Possible influences on GPS signal strength include position of the machine under canopy cover and time of day. As suggested by Veal et al. 2001, the use of GPS for detailed analysis of travel patterns needs further study.

Use of GPS on forest machines, in general and more specifically with the MultiDat, need more study before claiming the widespread applicability in monitoring environmental performance. The nature of data collection, every 15 seconds for example, cannot ensure how a machine traveled from point to point or how it is sitting at the time of observation. In addition, the GPS log only provides motion data for the center of the machine, not necessarily corresponding to ground contact of the track or wheel.

Discussion

This section will focus on the applicability and the limitations of the MultiDat system and report its congruence with the chosen methodology in this study.

Road Change Data Amendments

For the Cable Yarder study, some Road Change data was manually amended post-facto so as not to understate the impact of Road Change to productive time. During road changes, the yarder was typically left running while the operator assisted in laying out the next cable road. Among other activities, this involved moving (walking) the yarder and using the drums. Both of these actions could cause the motion sensor to jump above the threshold value, canceling any "stop code" entered and resulting in a record of productive time. When the sensor indicated motion below the threshold again, it prompted the operator for another delay code. When assisting with rigging, the operator was not tending to the MultiDat unit. After the 99 second prompt, the datalogger recorded a default stop code of No Response. Intermediary codes of productive time or No Response between the beginning and ending of a road change were amended to be analyzed as Road Change.

This must be viewed as a limitation of the datalogger in cable yarder applications. One purpose with the MultiDat is to eliminate human error by electronically controlling much of the data collection. However, this portion of the study took a lot of time to prepare the collected data for analysis. Post-facto data amendment in any situation can be cumbersome for a researcher or contractor and has the ability to impact results. Further, not all adjustments can be made with 100% certainty.

Data Quality and Operator Cooperation

Operator cooperation is of extreme importance and was exhibited in the Cable Yarder study and the Mastication Machine study. Although in the Cable Yarder study some errors in data collection were amended, some obvious errors were not in an attempt to avoid misrepresentation of the data. The most obvious case occurs on Oct. 22nd, where No Response accounted for 4.8% of the productive time (Table 2). Looking at the daily data, this is the result of two entries totaling 23 minutes and is interspersed among Interference delays and Productive Time measurements. It is impossible to determine post-facto how this delay should have been recorded. Although for the entire observation period No Response accounted for a low percentage of scheduled time, a daily value of 4.8% can have a rather large effect in determining the causes of non-productivity for a forest contractor.

Perhaps more telling are the lessons from the Mastication Machine study. No Response accounted for 7.4% of the total scheduled time (Table 3). Adding to this effect is the probable misuse of End Day by the operator, responsible for another 9.7% of scheduled time. Together, these two categories represent 17.1% of scheduled time. Most of these instances occurred either at the beginning or ending of the shift, more than likely when the operator was greasing the equipment or fueling.

The Grapple Skidder study employed a different methodology in that the operator directly controlled the accurateness of the data. For this study, 2:12:00 (14.6% of observed time) had to be eliminated from analysis due to erroneous input. However, relative percentages of productive and delay times were similar between the included and excluded data. It is hard to predict whether this percentage of error could be expected with similar methodology over a longer term study. Here, the operator only had to cooperate for a day and a half. Daily frustration may add to operator input errors. It is also plausible that as an operator became more familiar with the MultiDat and data entry became more part of the routine such errors would decline.

Limitations for Research

Production and efficiency research projects of forested machines usually occur at one of three levels: 1) activity sampling, 2) shift level studies, or 3) detailed time studies (Olsen and Kellogg, 1983).

Data collected by the MultiDat would provide a researcher with an opportunity to conduct activity sampling without being onsite. This could reduce the chance of bias on the part of the researcher or the operator. However, the research would miss observational data afforded only by being onsite during the operation.

The MultiDat also seems capable of providing reasonable shift level information with regards to productive time and delay recording. However, shift level studies often require additional information, ie. number of turns and number of pieces, that are not easily gathered with the MultiDat. These values are necessary inputs for equations in determining the cost efficiency of the machine.

Detailed time studies require intense, short duration collection of cycle time elements. Using the motion sensor methodology, the MultiDat does not afford the opportunity for research to drill down deep enough for detailed time studies. Cycle element times are only recorded to the nearest minute, generally overestimating elements less than a minute in duration. Times for delay data must be extracted from each cycle element time on an individual basis to uncover the ultimate barriers to production. One opportunity, not investigated in this study, could be to use the electric sensors to automate collection of certain cycle element times. However, with good operator cooperation, cycle time element information using only the motion sensor can be gathered rather quickly and sufficiently for most forest contractor needs.

Lastly, forest operations research, be it the result of activity sampling, shift level, or detailed time study, typically observes all the machines of an operation working in unison. Without multiple dataloggers, investigation of machine interactions in the same time frame would be impossible for an offsite analysis.

Conclusions

As for research purposes, several design features limit the applicability of the MultiDat in forest machine production and cost efficiency studies. For example in yarding/skidding studies, the inability to count number of turns and number of pieces by type make production estimates (in terms of volume or stem count) difficult by requiring a separate tabulation by the operator. Further, the non-synchronized internal clocks for activity codes and stop codes make analysis of detailed time study data problematic. Daily variations in start and stop times for shift hours, also occurring in everyday operations, make data cumbersome to analyze by requiring some manipulation.

As for forest contractor purposes, operator cooperation drives data quality results and thus, methodology should be designed to minimize the burden on machine operators. Use of the motion sensor, rather than operator input of activity codes, to determine machine production is the recommended method to gather simple efficiency data. The accompanying MultiDat software package is easy to understand and allows some flexibility for different objectives. It allows contractors to examine results generally at first and then to refocus their analysis on the areas of principal concern. The GPS tracking function provides location information that can be overlain on unit maps rather easily. Detailed analysis of travel patterns using GIS for analysis of environmental compliance requires further research.

This study tested both the intended (contractor level) and non-intended (research level and cable yarders) applications of the datalogger. The MultiDat performed sufficiently for its intended design. It provides an excellent tool for forest contractors to design and gather quick information regarding simple production figures for machines in different settings and over a range of operation types.

References

Brown, M.; Gumier, D.; Mercier, S.; Provencher, Y.; Turcotte, P. 2002. MultiDat and Opti-Grade: Two knowledge-based electronic solutions for managing forestry operations more efficiently. In Proceedings of the Woodfor Africa Forest Engineering Conference, Pietermaritzburg, South Africa, 2–3 July, 2002. Edited by L. Kellogg, B. Spong, and P. Licht. Department of Forest Engineering, Oregon State University, Corvallis, Oreg. pp. 45-49.

Olsen, E.; Kellogg, L. 1983. Comparison of time-study techniques for evaluating logging production. Transactions of the American Society of Agricultural Engineers 26(6): 1665-1668, 1672.

Veal, M.; Taylor, S.; McDonald, T.; McLemore, D.; Dunn, M. 2001. Accuracy of tracking forest machines with GPS. Transactions of the ASAE 44(6):1903-1911.