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Research Paper

Precision of tractor operations with soil cultivation implements using manual and automatic steering modes

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The influence of satellite guidance on the operating precision of a John Deere 7230R tractor with a Väderstad Carrier 350 soil cultivation multi-implement was evaluated. The tractor-implement unit was operated in three steering modes: conventional when the tractor was operated manually and two steering modes, one which relied on satellite navigation with free access to the SF1 correction signal and one using paid subscription for the SF2 correction signal. The automatic steering system consisted of John Deere AutoTrac parallel tracking, StarFire 3000 antenna and GreenStar 3 CommandCenter display. In each mode, operating precision was tested at three travel speeds: 3, 6 and 12 km h^{-1}. The experiment was carried out in 2013, on a farm in the region of Mazowsze, Poland, on a experimental plot with a surface area of 1.5 ha. Operating precision was analysed based on the combined operating width of two adjacent passes. Deviations from the optimal in-field operating routes, overlapped area (overlaps) and missed area (omissions) were determined.

1. Introduction

Precision steering systems for tractors and agricultural machines play a very important role in precision agriculture (Jingtao, Lei, Xiaoping, Taochang, & Xiaoguang, 2015; Liu & Wu, 2014; Neményi, Mesterházi, Pecze, & Stépán, 2003; Stafford, 2000). There are two basic approaches to automatic steering. In the first approach, the vehicle's surroundings are analysed with the use of cameras, digital analysis and image processing methods (Bayar, Bergerman, Koku, & Konukseven, 2015; Debain, Chateau, Berducat, Martinet, & Bonton, 2000; Xue, Zhang, & Grift, 2012). The second approach relies on GPS navigation (Bell, 2000; Cordesses, Cariou, & Berducat, 2000; Oksanen, 2015; Roberson & Jordan, 2014). There is also a third approach, combining both of the above. In a combined

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approach, farming machines are operated based on GPS navigation, whereas cultivation practices are supported by vision systems (Emmi, Gonzalez-de-Soto, Pajares, & Gonzalez-de-Santos, 2014; Li, Imou, Wakabayashi, & Yokoyama, 2009). This article focuses on the second these approaches: GPS navigation.

Agricultural machines that rely on GPS navigation are used for a variety of farming operations, including seeding, planting, fertilising, crop protection, cultivation and harvest (Batte & Ehsani, 2006; Bergtold, Raper, & Schwab, 2009; Oksanen, 2015; Ortiz, Balkcom, Duzy, van Santen, & Hartzog, 2013; Pilarski et al., 2002; Roberson & Jordan, 2014; Xiu, Lin, Wang, Li, & Yi, 2010). Automatic steering has numerous advantages, including repeatable path tracking (which facilitates multiple treatments during the growing season), making full use of the machine's operating width, reducing overlaps and easier operation during low visibility conditions (night time, fog). The operator of an automatically steered vehicle can fully control the quality of the farming operation (Holpp et al., 2013; Stoll & Kutzbach, 2000). Automatic steering also lowers the economic (Batte & Ehsani, 2006; Bergtold et al., 2009; Ortiz et al., 2013; Shinners, Digman, & Panuska, 2012) and environmental (Auernhammer, 2001; Batte & Ehsani, 2006) costs of agricultural practices.

The profits generated by automatic steering systems in agricultural machines are determined mainly by the quality of operation, namely the deviations between the vehicle's actual position and the planned route (Dunn, Powierski, & Hill, 2006; Han, Zhang, & Noh, 2002; Kayacan, Ramon, & Saeys, 2014; Keicher & Seufert, 2000). The above difference should be minimised, and this goal can be achieved in two ways. The first approach involves various methods that increase the precision with which the vehicle's position is determined. They include GPS data filtration, in particular Kalman filtering (Han et al., 2002; Mousazadeh, 2013), digital signal processing methods (Rovira-Más & Banerjee, 2013) and signal correction based on the receiver's location in the vehicle (Gomez-Gil, Alonso-Garcia, Gómez-Gil, & Stombaugh, 2011). In the second approach, steering relies on a high precision GPS receiver (Gan-Mor, Clark, & Upchurch, 2007; Rovira-Más & Banerjee, 2013). The two approaches can also be combined. Every method can entail additional costs: GPS subscriptions in the first approach, and the cost of electronic systems and additional calculation algorithms in the second approach.

The aim of this study was to compare the operating precision of a tractor-implement unit in the automatic steering mode with free or subscription GPS and in the manual steering mode. The findings of the study can help determine whether additional costs associated with GPS subscription are justified in view of their impact on operating speed and quality of the task.

2. Materials and methods

The experiment was carried out in 2013 in Maków/Załuzie, Mazowsze, Poland on a plot with a surface area 1.5 ha (geographical coordinates of the plot: 52°52′41.8″N 21°19′18.4″E). The farmed field was not situated in the immediate vicinity of any forest, and it did not feature any natural obstacles that could affect the quality (or stability) of the GPS signal and the machine's operating precision. The cultivated field had a slight slope with a maximum of 1° in the direction of the designated routes, and was therefore regarded as flat for the purposes of the study.

The tested machine unit comprised the John Deere 7230R tractor (169.2 kW) and the Väderstad Carrier 350 soil cultivation multi-implement (operating width of 3.19 m) (both supplied by ROL-BRAT, Maków, Mazowieckie, Poland). Path tracks were marked with two rods mounted 3.41 m apart on the implement's frame (Fig. 1).

The cultivation unit was operated in three modes: a manual steering mode and two automatic steering modes. Automatic modes relied on the StarFire 3000 GSBAS satellite navigation system. The tractor was equipped with John Deere AutoTrac parallel tracking, StarFire 3000 antenna and GreenStar 3 2630 CommandCenter display (all aforenamed equipment supplied by ROL-BRAT, Maków, Mazowieckie, Poland). The GPS receiver antenna was mounted at the centre of the cabin roof, that is along the axis of the cultivation unit. In the automatic steering mode, the in-field operating route was programmed by the operator. In the first automatic steering variant, the parallel tracking system relied on a SF1 correction signal with steering precision of ±230 mm (SF1 signal is paid once, when activated). The second variant relied on paid subscription for the SF2 correction signal with steering precision of ±50 mm. In each mode, the tractor was operated at three travel speeds (v_r) of 3, 6 and 12 km h^{-1}.

Vehicle steering precision can be influenced by the stability of the GPS signal. To eliminate possible signal disturbances, the tractor and the multi-implement were operated in the same area for all three steering modes. A rectangular test area, measuring 120 × 10 m, with measurement points, was mapped and is shown in Fig. 2. Measurement points were marked with ranging rods along longer sides of the rectangle, at 10 m intervals. Measurement sections had a length of 100 m.

In the manual steering mode, the first pass took place along the longer side of the rectangular test area (Fig. 3). The return pass was performed on the assumption that missed areas (omissions) should be avoided. The operating width of the two passes was determined using a measuring tape to the nearest 10 mm at each of the ten measurement points (Fig. 3). The passes were performed in three replications for each travel speed.

The measured distance was the combined width of two passes. The distance between measurement points was subtracted from the double width of passes to determine the width of overlapped area (overlaps) and missed area (omissions) according to the following formula:

$$b_{\eta_o} = 2 \cdot b - b_p \qquad [1]$$

where:

$b_{n/o}$ width of overlap/omission, mm; b – operating width of tractor-implement unit, mm; b_p – distance between measurement points, mm.

The values calculated in Eq. (1) represented the width of overlaps (positive result) or the width of omissions (negative result).