Agronomy Research **19**(1), 126–135, 2021
https://doi.org/10.15159/AR.20.239

Experimental research into new harrowing unit based on gantry agricultural implement carrier

V. Kuvachov[1], V. Bulgakov[2], V. Adamchuk[3], V. Kaminskiy[4], V. Melnik[5] and J. Olt[6,*]

[1]Dmytro Motornyi Tavria State Agrotechnological University, 18B Khmelnytsky Avenue, UA72310 Melitopol, Zaporozhye Region, Ukraine
[2]National University of Life and Environmental Sciences of Ukraine, 15 Heroyiv Oborony Str., UA03041 Kyiv, Ukraine
[3]National Scientific Centre, Institute of Mechanization and Electrification of Agriculture, 11 Vokzalna Str., Glevakha stl, Vasylkivsky Dist., UA08631 Kyiv Region, Ukraine
[4]National Scientific Centre, Institute of Agriculture of NAAS of Ukraine, 2b, Mashinobudivnikiv Str., Chabany vil., Kyiv-Svyatoshin Dist., UA08162 Kyiv Region, Ukraine
[5]Kharkiv Petro Vasylenko National Technical University of Agriculture, 44, Alchevskih Str., UA61002 Kharkiv, Ukraine
[6]Estonian University of Life Sciences, Institute of Technology, 56 Kreutzwaldi Str., EE51006 Tartu, Estonia
[*]Correspondence: jyri.olt@emu.ee

Received: October 6th, 2020; Accepted: December 11th, 2020; Published: December 16th, 2020

Abstract. From the point of view of energy saving, research into agricultural gantry units equipped with new implements specially adapted for operation in such systems and capable of efficiently functioning in controlled traffic (permanent lane) and wide span (gantry) systems is an important and topical issue in soil tillage science. The range of wide span systems includes harrowing units for fallow land tillage. This paper describes the experimental determination of the operating characteristics of the harrowing unit, in which a gantry implement carrier propels harrows for fallow land tillage, for the purpose of establishing the compliance of their parameters with the fundamental principles of the effective implementation of the controlled traffic and wide span soil management. The experimental investigations were done using strain-gauge and control-and-measuring equipment with analogue-to-digital conversion of the signals received from the sensing elements. An agricultural wide span unit with a track width of 3.5 m and harrows for fallow land tillage were investigated. The results show the harrowing unit is well adapted to operation in controlled traffic and wide span soil tillage systems and delivers high quality performance of the harrowing process. The latter effect is also due to the fact that the gantry travels on the compacted tracks which have a few surface irregularities compared to cultivated soil. The coefficient of variation of the draught force applied to the hook of the gantry during harrowing operations did not exceed 10%. This is evidence of the high stability (low variability) of the harrowing process, which has a positive effect on the motion stability of the harrowing unit based on the gantry tractor.

Key words: controlled traffic farming, harrowing unit, wide span system.

INTRODUCTION

The highly efficient development of controlled traffic and wide span soil management throughout the world is possible subject to wide implementation of the achievements by the science and technology progress (Rohde & Yule, 2003; Raper, 2005; McHugh et al., 2009; Tullberg, 2009; Kingwell & Fuchsbichler, 2011; Gasso et al., 2013 and 2014; Chamen, 2015; Antille et al., 2015 and 2019; Nadykto, 2019). In this context, the topic of searching for new soil tillage implements, machines and tools capable of efficiently operating in controlled traffic and wide span soil management systems becomes a top priority (Nadykto, 2012; Bulgakov et al., 2020b). Agricultural implements for soil surface tillage are among the representatives of the family of the soil tillage machines designed for operation in controlled traffic and wide span soil management systems. The harrows for fallow land tillage are one of the types of such implements. The functional capabilities of tillage implements, when used as part of agricultural wide span units for minimum soil cultivation, provide for the ripping of the soil surface layer within the agronomic zone of the field without carrying over the moisture to the surface, the stable operation of the tools with regard to the depth of their movement, the high quality of soil tillage etc. However, while the controlled traffic and wide span soil management is now widely accepted as a promising development trend, there is lack of attention to the experimental research into the new dedicated machines and implements designed in this area. The quality of the performed soil management operations depends on the design features of the employed agricultural implement, the mode of operation of the unit, the properties of the soil etc. In case of soil harrowing that includes also such factors, as the evenness of the surface in the farmed piece of land, the uniformity of the tilling depth and some other. Currently, in view of the introduction of new tilling implements operated as part of non-conventional (wide span) units, the industry faces a lack of the data required for validating the permissible variation of individual performance quality indices, and those data can be obtained only by means of special research. Alongside with that, one of the aims targeted by the introduction of wide span units into the controlled traffic soil management system is reducing the energy intensity of soil cultivation processes in view of the fact that the track width of such units (working span) can be very large. That said, in contrast to the conventional harrowing units that operate at acceptable travelling speeds of 8–15 km h^{-1}, the reduction of the energy data in case of wide span units can be achieved also through the lowering of their operational travel rates to values below 5 km h^{-1}. Thus, the research into the discussed gantry units has to aim at both finding out their main operation and process characteristics and developing the new implements (in particular, harrows) that provide for the required agronomic performance quality of the work process.

The detailed analysis of the results obtained during the experimental investigations of agricultural machines and implements as parts of controlled traffic and wide span soil management systems as well as the accumulated practical knowledge are of invaluable importance for science.

Many scientists Chamen et al. (1992, 1994), Taylor (1994), Bochtis et al. (2010), Onal (2012), Pedersen et al. (2013, 2016), Bulgakov et al. (2017, 2018, 2019), Chamen (2000) have made a great input into the development and promotion of the controlled traffic and wide span soil management. At the same time, the analysis of the research results published by them has revealed that their papers still feature insufficient attention to the issue of fundamental experimental research into the characteristics of wide span soil tillage units based on gantry agricultural implement carriers.

As regards the use of the latter with implements adapted for operation with them, a design of interest is the harrow with tines equipped with subsurface segment blades (Adamchuk et al., 2020). In all the rows of tines the blades are installed in the horizontal plane at the same angle of inclination. But such a harrow design does not provide for the efficient extirpation of weeds (weed stalks and roots become wound on the tools). The difficulty in the penetration of these harrowing tools into the soil, especially in case of the latter's increased compactness, which results, overall, in the insufficient quality of the soil tillage with regard to the depth of tillage, is another problem faced, when using the said type of harrows.

Another design of harrow for soil tillage (Bulgakov et al., 2020a) has been developed for arid soil management conditions. In this design, the subsurface segment blades in the first row are set in the longitudinal vertical plane, the blades in the second row are set at a greater inclination to the horizontal plane than the blades in the last rows. According to the authors, such a harrow design solution provides for the high quality of soil tillage and is appropriate for use in the agricultural wide span gantry units that travel on permanent traffic lanes.

The aim of the research described in this paper was to establish the conditions required for the efficient use of harrows in fallow land tillage and to determine the optimum parameters and characteristics for the harrowing unit based on a gantry agricultural implement carrier operating in a controlled traffic and wide span soil management system.

MATERIALS AND METHODS

The experimental investigations were carried out standard techniques and the ones specially developed by the authors, with the use of up-to-date strain-gauge and control-and-measuring equipment with analogue-to-digital conversion of the signals received from the installed strain-gauge and other slide-wire transducers. The obtained test experiment data were processed on the PC with the use of the probability calculus, the regression analysis as well as the correlation spectrum analysis.

During the experiments, the following tasks were pursued: to determine the longitudinal irregularity profiles of the permanent process lane and of the cultivated soil before and after harrowing, the moisture content and density of the soil, and the soil tillage depth.

The equipment used was a wide span gantry agricultural implement carrier with a track width of 3.5 m, the design of which had been developed by the authors (Fig. 1), and harrows designed for fallow land tillage (Adamchuk et al., 2020).

Figure 1. Harrowing unit based on gantry agricultural implement carrier.

The structural layout of the tools installed in the harrow for fallow land tillage is presented in Fig. 2. In this harrow, the front row tines feature flat segment blades installed at their ends in the longitudinal vertical plane. The tines in the second and all the remaining rows have at their ends flat segment blades installed in the horizontal plane at an angle of α. Starting from the third row and further, the angle α, at which the flat segment blades are installed, decreases.

The area of the flat segment blades is determined by their linear dimensions $a \times b$. The depth, at which the tines of the harrow under consideration travel in the soil, is designated h.

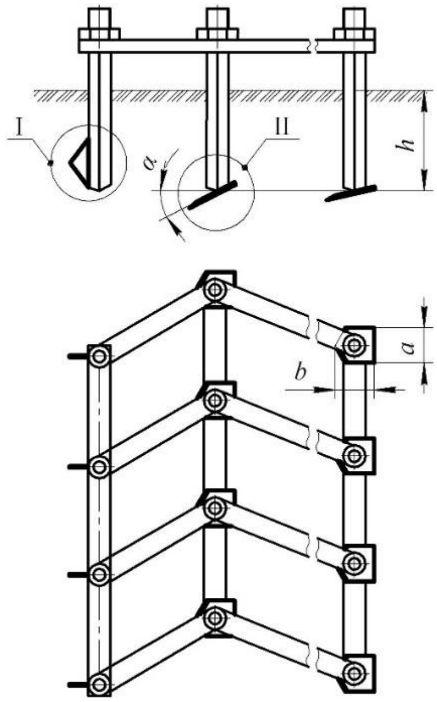

Figure 2. Design of harrow for fallow land tillage: I – first row tines; II – second row tines.

The use of the tines that have flat segment blades fixed at their ends to facilitating the efficient cutting of weeds was a distinctive feature of the harrow used in the experimental investigations. The dimensions of the flat segment blades were selected so they would not obstruct the penetration of the tines into the soil to the required depth h, and would also efficiently rip the soil to the pre-set depth without carryover of its lower moisture-laden layer to the field surface, thus achieving the necessary quality of soil tillage.

The harrowing unit used in the field experiments was attached to the gantry agricultural implement carrier, which was fitted with 9.5R32 tyres. The experiments were carried out with the use of a specially equipped field laboratory.

Figure 3. Automated field surface profile recorder.

During the experiments, the irregularities of the longitudinal profile of the permanent process lane and the cultivated soil were recorded with a high accuracy automated profile recorder developed by the authors (Fig. 3).

The draught resistance of the harrows was determined with the use of a traction strain-gauge link attached to the SA-type dynamometric automatic hitch specially adapted for this purpose (Fig. 4).

The cultivated soil profile irregularities and the draught resistance of the harrowing tools, were recorded with the use of an integrated measuring and recording unit based on an analogue-digital converter and a personal computer (PC) loaded with the respective software programmes (Fig. 5).

Figure 4. SA-type dynamometric automatic hitch with traction strain-gauge link.

Figure 5. Integrated measuring and recording unit.

The records obtained in the process of the experiments were transferred in the form of digitised data into the Mathcad Prime 5.0 environment, where the calculations were performed. Mathcad was used to calculate the following statistical characteristics: mean value; root-mean-square (standard) deviation; variance; coefficient of variation; sample mean accuracy; normalised correlation function; normalised spectral density. The above-mentioned statistical parameters were determined with the use of techniques described by Brandt (2014). The error of direct parameter measurement did not exceed 1%.

The moisture content of the soil was determined in accordance with the standard thermostat-oven weighing method. The soil tillage depth was with a specially developed depth gauge at 10 locations on the diagonal of the cultivated land lot.

The experimental research was carried out on dark chestnut (*Kastanozem*) lightly alkaline (*Solonetz*) type of soil. The share of the fractions with soil clod diameters of up to 2.0 cm was at least 80%. The soil cloddiness (presence of lumps with diameters greater than 4 cm) was maximum 2–3 lumps per square metre. The cultivated soil used in the described experiments was a field prepared for sowing.

During the experiments, the mean value of the soil moisture content within the 0–10 cm layer was 26.8%, of the soil dry bulk density - 1.23 Mg m^{-3}.

The experiments were carried out in a 50 m long test plot at speeds ranging from to 3.6, 4.1 and 4.5 km h^{-1}. At each of these travelling speeds, the experiments with data recording were performed in 3 replications, with the harrowing unit moving in both directions. Hence, the total number of experiments exceeded 30.

RESULTS AND DISCUSSION

Analysis of the experimental data shows that the profile of the permanent process lane is smoother than the profile of the cultivated soil after its tillage. For example, the root mean square deviation of the harrowed soil profile was ±1.36 cm, while for the profile of the lane it was ± 0.84 cm, which is 1.6 times less (Fig. 6).

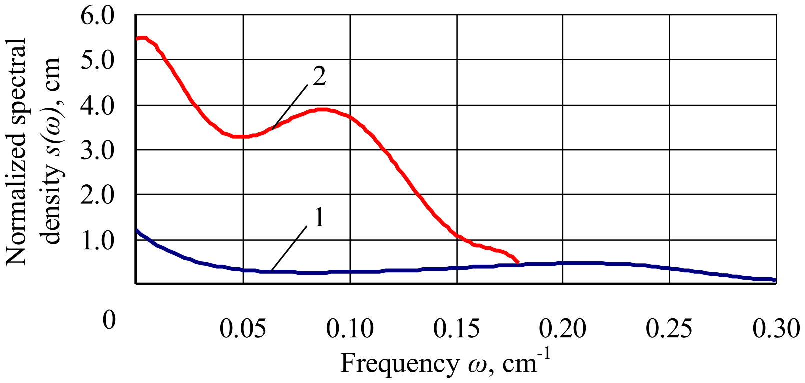

Figure 6. Diagrams of normalised spectral density of irregularities in longitudinal profiles of permanent process lane track (1) and harrowed soil (2).

As regards their inherent structure, the irregularities in the profile of the permanent process lane are characterized by the function that together with random components contains also harmonic ones represented by damped periodic oscillations of the normalised correlation function (Fig. 7). According to it, the correlation length between the ordinates of the irregularities in the profile of the permanent process lane was circa 0.18 m, which corresponds to the spacing of the lugs on the tyres of the gantry agricultural implement carrier, the latter being equal to 0.175 m.

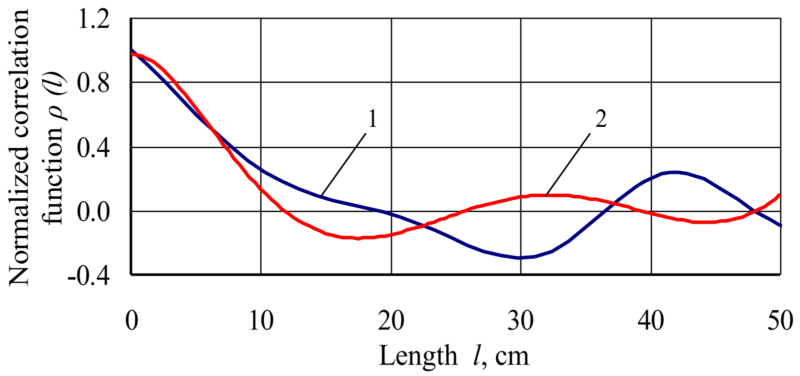

Figure 7. Diagrams of normalised correlation function of irregularities in longitudinal profiles of permanent process lane track (1) and harrowed soil (2).

The spectrum of the frequencies representing the random function of the irregularities in the profile of the permanent process lane is specified by the normalised spectral density of the ordinates of the said irregularities (Fig. 6). It has been established by analysing the normalised spectral density of irregularities in the profile of the permanent process lane that the cut-off frequency for this process was approximately 0.3 cm^{-1}. The main part of the variance of the track profile irregularity ordinate oscillations is concentrated within the range of frequencies 0–0.3 cm^{-1}. Their root mean square deviation corresponds to the height of the lugs on the tyres of the gantry agricultural implement carrier, which was 0.03 m.

The above analysis of the characteristics observed in the irregularities of the profile of the permanent process lane, on which the gantry agricultural implement carrier travels repeatedly many times, gives evidence of the fact that these irregularities are generated by the parameters of the lugs on its tyres.

The inherent structure of the irregularities in the profile of the cultivated lot of cultivated soil is to some extent different from that of the irregularities in the profile of the permanent process lane (Fig. 7). The correlation distance between the ordinates of the irregularities in the profile of the harrowed cultivated soil was about 12 cm. Such a profile of the agronomic background is typical of the fields cultivated for the purpose of sowing many agricultural crops.

As distinct from the irregularities generated by the tyres on the wheels of the gantry agricultural implement carrier in the profile of the permanent process lane tracks, the profile of the harrowed lot of agronomic background has a lower-frequency pattern (Fig. 7). The correlation length between the ordinates of the irregularities of the permanent process lane tracks is equal to about 0.175 cm.

The oscillations of the draught resistance offered by the harrowing implement represent a random function, in which harmonic components are absent (Fig. 8). The main variance spectrum of the tractive resistance oscillations is concentrated within the range of frequencies 0–3.5 s^{-1}.

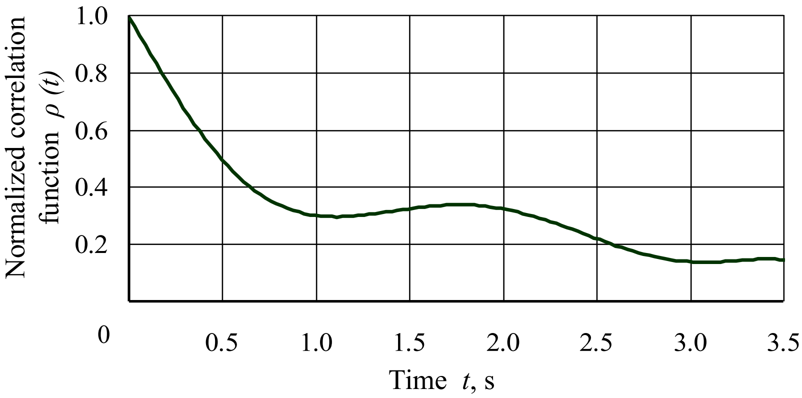

Figure 8. Diagram of normalised correlation function of oscillations in draught resistance of harrowing implement.

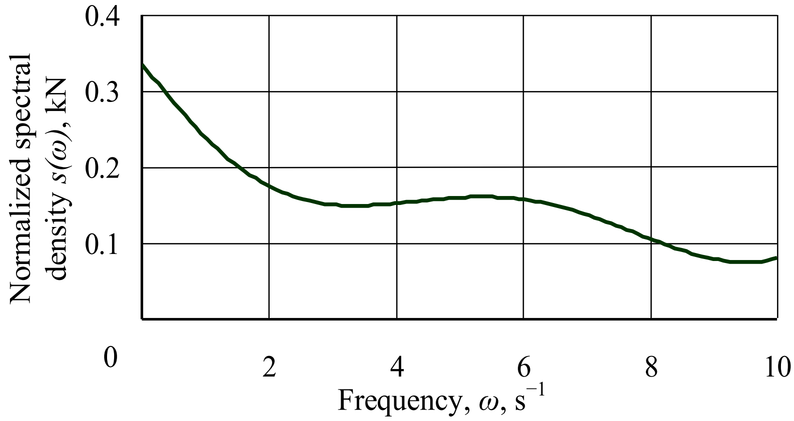

Figure 9. Diagram of normalised spectral density of oscillations in draught resistance of harrowing implement.

The energy of the oscillation variance of the draught resistance offered by the harrow was equal to 0.027 kN^2, and the root mean square deviation σ_{Ph} was equal to 0.166 kN (Fig. 9). If the mean value of the draught resistance P_h produced by the three harrows in the gantry unit is equal to 1.71 kN, the coefficient of variation k of its oscillations in the process of harrowing is equal to 9.76% [$k = (\sigma_{Ph}\ 100)\ (P_h)^{-1} = (0.166 \cdot 100)\ (1.71)^{-1} = 9.76\%$]. Such a result is a good sign of high stability (low variability) of the process of harrowing using the gantry agricultural implement carrier.

The quality indices of the soil harrowing performed with the use of the gantry agricultural implement carrier equipped with harrows for fallow land tillage comply with the agrotechnical requirements applied to this process operation (Bulgakov et al., 2020a). In particular, the deviation of the actual cultivation depth h from the target value does not exceed ± 1 cm, while the height of the ridges on the agronomic background does not exceed 2 cm.

CONCLUSIONS

1. As a result of the experimental investigations carried out on a gantry agricultural implement carrier and a harrow for fallow land tillage, it has been proved that the implement is well adapted to the operation in controlled traffic and wide span soil management systems and delivers a high quality tillage result. The latter fact is also due to the gantry agricultural implement carrier travelling on the compacted tracks of the permanent process lane, the irregularity profile of which has a lower-frequency pattern as compared with the longitudinal profile of the harrowed soil.
2. The design of the harrow for fallow land tillage has a positive effect on the variation of its draught resistance. It has been established that the oscillations of the draught resistance produced by the harrowing implement represent a random function, in which harmonic components are absent. The coefficient of variation of the oscillations in the resistance force applied to the hook of the gantry agricultural implement carrier during harrowing work does not exceed 10%. That is indicative of the high stability (low variability) of the soil harrowing process. This characteristic, in its turn, provides for lower variation of the moment of resistance applied to the running gear of the gantry tractor, which, finally, has a positive effect on the stability of motion of the gantry agricultural implement carrier-based harrowing unit under consideration.
3. The operation of the agricultural gantry-carrier harrowing unit at a low rate of travel (less than 5 km h^{-1}) does not impair the quality indices specified for the work process under consideration by the agronomic standards. That renders possible significantly reducing in the future the energy intensity of the soil cultivation processes based on the use of gantry-carrier units travelling on the tracks of the permanent process lane, by means of reducing the operational travel rates for units with increased working widths.

REFERENCES

Adamchuk, V., Bulgakov, V., Nadykto, V. & Ivanovs, S. 2020. Investigation of tillage depth of black fallow impact upon moisture evaporation intensity. *Engineering for Rural Development* **19**, 377–383. doi:10.22616/ERDev.2020.19.TF090

Antille, D.L., Peets, S., Galambošová, J., Botta, G.F., Rataj, V., Macak, M., Tullberg, J.N., Chamen, W.C.T., White, D.R., Misiewicz, P.A., Hargreaves, P.R., Bienvenido, J.F. & Godwin, R.J. 2019. Review: Soil compaction and controlled traffic farming in arable and grass cropping systems. *Agronomy Research* **17**(3), 653–683. doi: 10.15159/AR.19.133

Antille, D.L., Chamen, W.C.T. & Tullberg, J.N. 2015. The potential of controlled traffic farming to mitigate greenhouse gas emissions and enhance carbon sequestration in arable land: a critical review. *In Transactions of the ASABE* **58**(3), 707–731.

Bochtis, D.D., Sørensen, C.G. & Busatob, P. 2010. Tramline establishment in controlled traffic farming based on operational machinery cost. *Biosystems Engineering* **107**(3), 221–231.

Brandt, S. 2014. Data analysis: Statistical and computational methods for scientists and engineers, eth ad., Springer International Publishing, 523 pp. doi: 10.1007/978-3-319-03762-2

Bulgakov, V., Adamchuk, V., Kuvachov, V., Arak, M. & Olt, J. 2017. Study into movement of wide span tractors (vehicles) used in controlled traffic farming. – In: *Proceedings of the 28th DAAAM International Symposium: 28th DAAAM International Symposium "Intelligent Manufacturing and Automation"* (Ed. B. Katalinic). 2017 November 08–11, Zadar, Croatia, Vienna, Austria: DAAAM International Vienna, 0199−0208.10. 2507/28th.daaam.proceedings.027Bulgakov, V., Kuvachov, V. & Olt, J. 2019. Theoretical Study on Power Performance of Agricultural Gantry Systems. – In: *30th International DAAAM Symposium "Intelligent Manufacturing & Automation*" (Ed. B. Katalinic). Zadar, 2019 October 23.–26, Vienna, Austria: DAAAM International: 0167−0175. 10.2507/30th.daaam.proceedings.022

Bulgakov, V., Melnik, V., Kuvachov, V. & Olt, J. 2018. Theoretical Study on Linkage Unit of Wide Span Tractor. – In: *Proceedings of the 29th DAAAM International Symposium* (Ed. B. Katalinic). Vienna, Austria: DAAAM International Vienna, 0180-0189. 10.2507/29th.daaam.proceedings.026

Bulgakov, V., Nadykto, V., Kaminskiy, V., Ryzhylo, Z., Volskyi, V. & Olt, J. 2020a. Experimental research into effect of harriwing unit´s operating speed on uniformity of cultivation depth during tillage in fallow field. *Agronomy Reseach* **18**(3), 1962–1972. doi: 10.15159/AR..20.200

Bulgakov, V., Olt, J., Kuvachov, V & Smolinskyi, S. 2020b. A theoretical and experimental study of the traction properties of agricultural gantry systems. *Agraarteadus* **31**(1), 10–16. doi: 10.15159/jas.20.08

Chamen, T. 2015. Controlled traffic farming – from worldwide research to adoption in Europe and its future prospects. *Acta Technologica Agriculturae Nitra* **18**(3), 64–73. doi: 10.1515/ata-2015-0014

Chamen, W.C.T. 2000. A new methodology for weed control and cereal crop production based on wide span vehicles and precision guidance: Biotrac. *Processing 4th EWRS workshop on physical weed control* (20–22 March 2000). Netherlands, 51–55.

Chamen, W.C.T., Dowler, D. & Leede, P.R. 1994. Design, operation and performance of a gantry system: Experience in Arable Cropping. *Journal of Agricultural Engineering Research* **59**, 45–60.

Chamen, W.C.T., Watts, S.W., Leede, P.R. & Longstaff, D.J. 1992. Assessment of a wide span vehicle (gantry) and soil and cereal crop responses to its use in a zero traffic regime. *Soil & Tillage Research* **24**(4), 359–380. doi: 10.1016/0167-1987(92)90119-V

Gasso, V., Sørensen, C. & Pedersen, H. 2014. An environmental life cycle assessment of controlled traffic farming. *Cleaner Production* **73**, 175–182.

Gasso, V., Sørensen, C.A.G. & Oudshoorn, F.W. 2013. Controlled traffic farming: A review of the environmental impacts. *European Journal of Agronomy* **48**, 66–73.

Kingwell, R. & Fuchsbichler, A. 2011. The whole–farm benefits of controlled traffic farming: An Australian appraisal. *Agricultural Systems* **104**(7), 513–521.

McHugh, A.D., Tullberg, J.N. & Freebairn, D.M. 2009. Controlled traffic farming restores soil structure. *Soil Tillage Research* **104**(1), 164–172, doi: 10.1016/j.still.2008.10.010

Nadykto, V. 2019. *Modern development paths of agricultural production: Trends and innovations*. Tavria State Agrotechnological University, Melitopol, 814 pp. doi: 10.1007/978-3-030-14918-5

Nadykto, V. 2012. Role of tractors' energy saturation rate in making of their range. *Tractors and agricultural machinery* **3**, 16–21.

Onal, I. 2012. Controlled traffic farming and wide span tractors. *Agricultural Machinery Science* **8**(4), 353–364.

Pedersen, H.H., Oudshoorn, F.W. & McPhee, J.E. 2016. Wide span – re–mechanising vegetable production. *XXIX International horticultural congress on horticulture: sustaining lives, livelihoods and landscapes*: international symposia on the physiology of perennial fruit crops and production systems and mechanization, precision horticulture and robotics Book Series: *Acta Horticulturae* **1130**, 551–557.

Pedersen, H.H., Sørensen, C.G. & Oudshoorn, F.W. 2013. User requirements for a wide span tractor for controlled traffic farming: *CIOSTA XXXV Conference «From effective to intelligent agriculture and forester». International commission of agricultural and biological engineers* (3–5 July 2013, Section V). Billund, Denmark, pp. 134–136.

Raper, R.L. 2005. Agricultural traffic impacts on soil. *Terramechanics* **42**, 259–280.

Rohde, K. & Yule, D. 2003. Soil compaction and Controlled Traffic Farming research in Central Queensland. *Proceedings ISTRO* **16**, 1020–1027.

Taylor, J.H. 1994. Development and Benefits of Vehicle Gantries and Controlled–Traffic Systems. In: Soane B.D., van Ouwerkerk C.(Eds). *Soil Compaction in Crop Production*. Elsevier Science Publishers, B., Amsterdam, pp. 521–537.

Tullberg, J.N. 2009. Avoiding soil compaction in CA: controlled traffic systems for mechanized conservation agriculture and their effect on greenhouse gas balances In: *Proceedings 4*th *World Congress on Conservation Agriculture* (February 2009, New Delhi), pp. 85–190.