THEORETICAL PREMISES FOR ENHANCEMENT OF EFFICIENCY IN THE USE OF REVERSIBLE PLOUGHS

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Abstract. *Theoretical analysis has been undertaken to determine the effect of the plough's structural layout on the total length of the tractor-implement unit's turning path. Basing on the results of the analysis, the utility of employing a reversible plough instead of a conventional one has been assessed. Eventually, it has been found that, when ploughing a 68.2 m wide land with an area of 8.2 hectares, the total length of the path of travel on the headlands is 1980 m for the reversible plough unit and 2035 m for the conventional plough unit, which is an increase by 2.7%. At an average manoeuvring speed of 1.75 m/s (6.3 km/h), the total amount of time spent for turning by a unit with conventional ploughing tools will be greater by mere 0.5 min. If the ploughed land is magnified by almost 1.5 times (12.0 hectares instead of 8.2), the width of the field will reach 100 m. In this case, the ploughing unit with a conventional plough will travel an 850 m longer path on the headlands. At the above-mentioned average headland manoeuvring speed of 1.75 m/s the increase of time spent by this type of tilling unit for turning will amount to just 8 min. The only advantage of the reversible plough over the conventional one is the opportunity to avoid the appearance of crown ridges and dead furrows when tilling the field. Meanwhile, it is to be noted that with a sufficient qualification of the machine operator the said advantage of the newer tilling implements can be levelled down. Considering the equal productivity of the compared tilling units, a negligible difference between their rates of non-productive expenditure of working time as well as taking into account the infrequent performance of ploughing, i.e. once in several years, in view of the considerably (several times) higher cost of a reversible plough, the acquisition of the latter presents an economically inadvisable option.*

KEY WORDS*: PLOUGHING, PLOUGH, REVERSIBLE PLOUGH, TILLING UNIT, HEADLAND, FURROW.*

Introduction

Statement of problem. Lately the agricultural industry has seen ever wider introduction of reversible ploughs, the main advantage of which is the ability to work the field without producing the crown ridges and dead furrows.

One would think that such evidently efficient performance attributes of this kind of tillage implements should promote the gradual displacement of conventional ploughs from the market. But, decisive preference can be given to reversible ploughs only following their thorough theoretical as well as field study with results that confirm the said attributes. Moreover, all this research is to be done taking into consideration the various types of tractor-implement units with reversible ploughs, tilled land dimensions, tilling unit travelling patterns etc.

At the same time, it should be noted that, whereas the tilling tractor-implement unit with a reversible plough uses the shuttle travelling pattern in its work process on productive runs, it still has to make loop turns at the headlands. While this type of tractor-implement unit manoeuvring is more difficult to perform than, for example, loop-free turning.

Also, although tilling with the use of a conventional plough can result in the development of crown ridges and dead furrows with all the ensuing well-known adverse effects, but the practice proves that these drawbacks can be virtually completely eliminated providing that the qualification of the tractor-implement unit operator is sufficiently high. That requires abiding by the scientifically grounded and methodically tried and tested recommendations described in the available publications [1-3].

The aim of this study is to substantiate theoretically the need to use efficiently reversible ploughs as compared to the conventional ones.

Materials and methods

The research has been carried out with the use of the methods supported by the theory of operating tractor-implement units, the theoretical mechanics, the higher mathematics, the principles of program construction and PC-assisted numerical computation.

Results and discussion.

For the purpose of the theoretical study, two tilling tractor-implement units have been taken as the subjects of research and compared to each other. The first of them comprises a Class 3 tractor with an articulated frame and a rear-mounted five-bottom plough. The second tractor-implement unit consists of the identical unitising power unit (tractor) and a rear-mounted reversible five-bottom plough, which has the same working span as in the first case – 1.75 m.

We have carried out the analysis and PC-assisted numerical computation of the total length of the path travelled by each of the above-mentioned compared tractor-implement units on the headlands, when they perform the tilling of lands with the same areas.

Provided that the average working speeds of travel of the said tilling units on the headlands are equal (which is absolutely realistic in the ordinary operation conditions), the difference between the found total lengths of travelling during the manoeuvres will in practice define that non-productive shift time consumption, which just indicates the advantage of one of the compared tractor-implement unit options over the other one.

Further, in order to perform the investigation it is necessary to determine analytically the width of the experimental field plot (land) required for the operation of the compared tilling tractor-implement units. To do that, the following analytical dependence can be used:

$$C_{opt} = \sqrt{16R_t^2 + 2B_sL_f}\,, \qquad (1)$$

where R_t – minimum radius of turning of tractor-implement unit (m); B_s – working span of tilling unit (m); L_f – length of land (experimental plot) (m).

The minimum turning radius R_t of the tractor-implement unit on the basis of an articulated frame tractor can be found with the use of the following formula:

$$R_t = \left(\frac{L}{2}\right) ctg \frac{\alpha}{2}, \qquad (2)$$

where L – longitudinal base length of tractor (m); α – maximum frame articulation of the power unit (i.e. such type of tractor) (deg).

Using formula (2), it is easy to calculate the minimum turning radius R_t of the tilling tractor-implement units, which at the following design parameters of the above-mentioned tractors: L = 2.86 m and α = 30° will be equal to R_t = 5.3 m.

To continue our investigation, we assume that the length of furrow in the field is L_f = 1200 m. Taking into account the fact that the five-bottom ploughs selected for the study have a working span width of B_s = 1.75 m, from expression (1) we obtain, after substituting in it the assumed values of design parameters: C_{opt} = 68.2 m.

When tilling a land with a width of C_{opt}, each tractor-implement unit completes n_c turns. At the same time, the ratio $\frac{C_{opt}}{B_s}$ representing the number of working runs performed by the tilling unit on the headland must be a whole number. In view of that, the number of turns n_c can be determined with the use of the following formula:

$$n_c = Integer\left(\frac{C_{opt}}{B_s}\right) - 1. \qquad (3)$$

The tilling unit with a reversible plough will perform only loop turns (n_l = n_c), each having a length of L_{lu} defined as follows:

$$L_{lu} = (6{,}0 \div 8{,}0)R_t + 2E, \qquad (4)$$

where E – length of the unit's exit from the land.

In our case E = 7.5 m.

For the following calculations expression (4) can be assumed in the following form:

$$L_{lu} = 7R_t + 2E. \qquad (5)$$

Using expressions (3) and (5), we can find the total length of the loop turns performed by the tractor-implement unit with a reversible plough as the sum of L_{lu}, i.e. as follows:

$$\sum_{k=1}^{n}(L_{lu})_k = L_{lu}n_l = (7R_t + 2E)\left[Integer\frac{C_{opt}}{B_t} - 1\right]. \qquad (6)$$

The tilling tractor-implement unit with a conventional plough initially also performs loop turns. It continues doing them until the following condition is met:

$$n_{lm} = B_s \geq 2R_t, \qquad (7)$$

where n_{lm} – number of working runs during the performance of loop turns.

The number of loop turns (n_{lc}) will be equal to:

$$n_{lc} = Integer\left(\frac{R_t}{B_s}\right) - 1, \qquad (8)$$

while their total length will be equal to:

$$\sum_{k=1}^{n}(L_{ll})_k = L_{lc}n_{lc} = (7R_t + 2E)\left[Integer\left(2\frac{R_t}{B_s}\right) - 1\right]. \qquad (9)$$

After condition (7) becomes fulfilled, the tilling unit will start performing already loop-free turns doing straight runs with a length of X_l. The length L_{mnl} of each such manoeuvre of the tilling tractor-implement unit can be defined as follows:

$$L_{mnl} = (1{,}4 \div 2{,}0)R_t + 2E + X_l. \qquad (10)$$

For the calculation purposes, we can express L_{xnl} in the following form:

$$L_{mnl} = 1{,}7R_t + 2E + X_l. \qquad (11)$$

The number n_{nl} of the loop-free turns performed by the tilling tractor-implement unit will be equal to:

$$n_{nl} = n_c - n_{lc} = Integer\left(\frac{C_{opt}}{B_s}\right) - 1 - Integer\left(\frac{2R_t}{B_s}\right) + 1 = \\ = Integer\left(\frac{C_{opt}}{B_s}\right) - Integer\left(\frac{2R_t}{B_s}\right). \qquad (12)$$

As regards the total length of the straight runs on the headlands, it will be calculated as follows:

$$\sum_{k=1}^{n} X_l = B_s \sum_{k=0}^{n_{nl}} \left(n_{nl}\right)_k . \qquad (13)$$

Using expression (13), we can find the total length of the loop-free turns performed by the tilling tractor-implement unit equipped with a conventional plough:

$$\sum_{k=1}^{n} \left(L_{mnl}\right)_k = \left(1,7R_t + 2E\right)\left[Integer\left(\frac{C_{opt}}{B_s}\right) - Integer\left(\frac{2R_t}{B_s}\right)\right] + \\ + B_s \sum_{k=0}^{n_{nl}} \left(n_{nl}\right)_k . \qquad (14)$$

Combining expressions (9) and (14), we obtain the formula that allows determining the total length L_G of the turns performed by the tractor-implement unit equipped with a conventional plough. It will be equal to:

$$\sum_{k=1}^{n} \left(L_{cg}\right)_k = \left(7R_t + 2E\right) n_{lc} + \left(1,7R_t + 2E\right) n_{nl} + B_s \sum_{k=0}^{n_{nl}} \left(n_{nl}\right)_k . \qquad (15)$$

The computation of the obtained analytical expressions (6) and (15) carried out on a PC with the use of a specially developed programme enabled plotting the graphical representations of the functions of the total lengths of the turns performed by tractor-implement units equipped with conventional and reversible ploughs.

As we can see from the presented graphs, when the width C_{opt} of the tilled land is up to 65 m, the total lengths of turns of the tilling tractor-implement units under consideration is virtually the same. When the width C_{opt} exceeds 65 m, the total length of turns travelled by the unit with a conventional plough starts increasing at a higher rate than that of the unit equipped with a reversible plough.

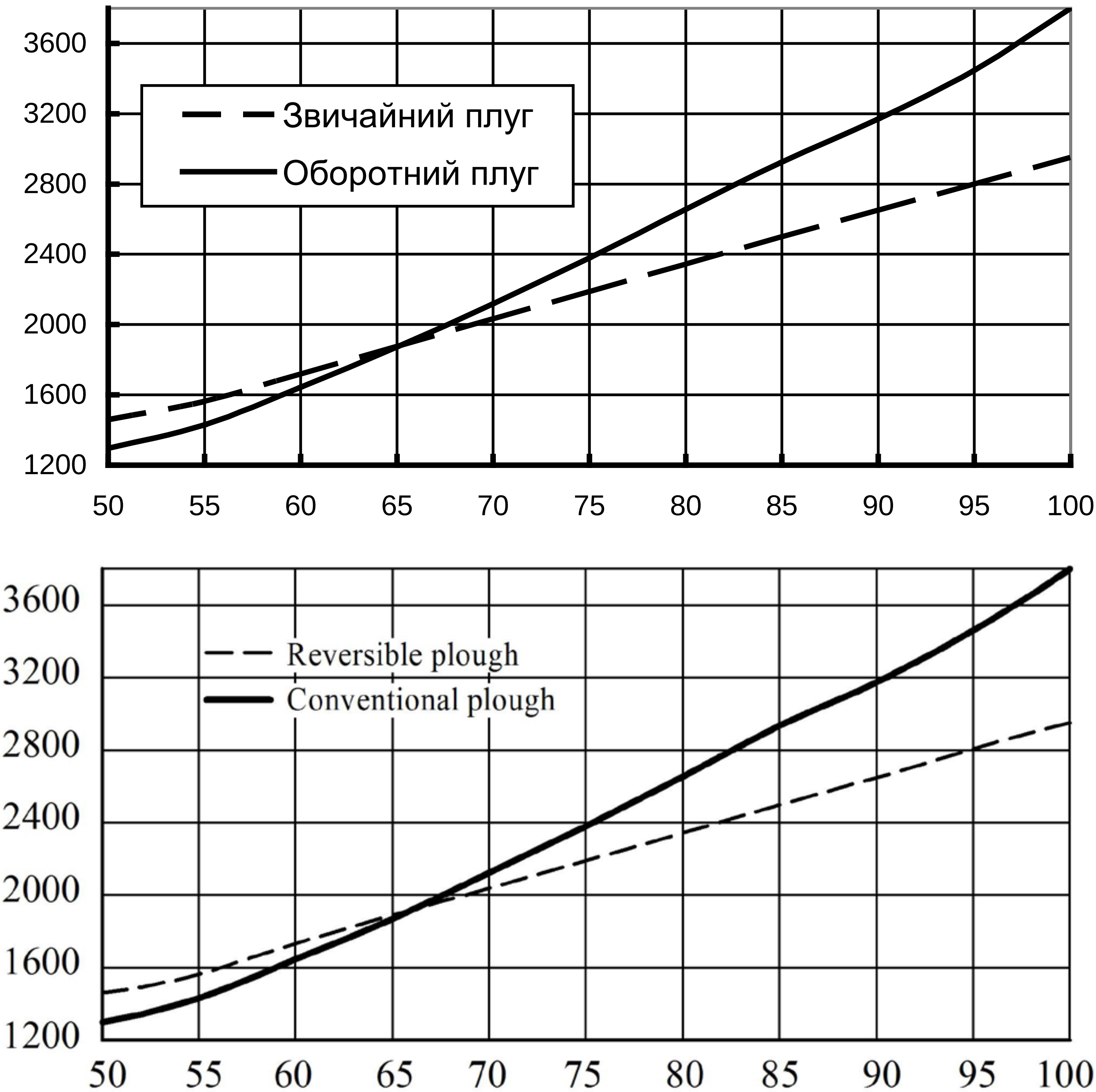

Fig. Total length of turns travelled by tilling tractor-implement units with: reversible (L_{ll}) and conventional (L_{cg}) ploughs as function of tilled land width C_{opt}

Thus, when tilling a land with a width of C_{opt} = 68.2 m and an area of 8.2 ha, the total length of turns travelled by the tilling unit with a conventional plough is equal to 2035 m, but with a reversible one – 1980 m. Nevertheless, this means a reduction by just 55 m or 2.7%.

In addition, we have found that the travelling speed of a tilling tractor-implement unit on headlands varies within 1.5…2.0 m/s. Hence, at an average manoeuvring speed of 1.75 m/s (6.3 km/h) the total time spent for turns by a unit equipped with a conventional plough will be greater by mere 0.5 minutes. In effect, when operating tilling tractor-implement units in ordinary conditions, the said time difference can completely disappear, since the average travel rate during a loop turn is lower than that during a loop-free turn.

After increasing the tilled land area by almost 1.5 times (i.e. 12.0 ha instead of 8.2 ha), the land width will be equal to 100 m. In this case, the tilling tractor-implement unit equipped with a conventional plough will travel on the headlands additional 850 m. Taking into account the above-mentioned average manoeuvring speed (1.75 m/s), the increase of the time spent for turns by this tilling unit will amount to just 8 minutes. On a working shift time balance scale, this time increase is negligible.

Moreover, it is to be taken into account that already the studies of recognized soil scientist W.R. Williams [4] proved that the main aim of ploughing was the periodical (but not annual!) restoration of the structural strength of soil. Hence, a scientifically grounded system of tillage should include ploughing performed once in several years. Thus, it is quite obvious that the tilling with a reversible plough, the cost of which is several times higher than the cost of a conventional plough, is not always an economically sound option. Such opinions have more than once been passed in scientific publications [5].

Conclusions

1. The apparent advantages of the reversible plough over the conventional one, which can be seen in the possibility to till the field without producing crown ridges and dead furrows, are not always feasible, for example, on account of the insufficient

qualification of the operator that performs the tillage with the use of a state-of-the-art tilling tractor-implement unit.

2. The completed analytical investigation has shown that, along with the virtually equal productivity of the compared tilling tractor-implement units equipped with conventional and reversible ploughs, a negligible difference is observed in the non-productive expenditure of working shift time by the units under consideration.

3. The results of PC-assisted numerical calculations have shown that, when the width of the tilled land C_{opt} is up to 65 m, the total length of turns travelled by the tilling units with conventional and reversible ploughs is virtually the same. When the width C_{opt} exceeds 65 m, the tilling unit equipped with a conventional plough travels a greater total length. But, the calculations have also indicated that at an average manoeuvring speed of 1.75 m/s (6.3 km/h) the total time spent for turning by the unit with a conventional plough will be greater by mere 0.5 minutes.

4. The analytical investigation has also found that if the tilled land area is increased by almost 1.5 times (i.e. 12.0 ha instead of 8.2 ha), the tilling tractor-implement unit equipped with a conventional plough will travel on the headlands additional 850 m, which is equivalent to an increase of the time expenditure by just 8 minutes, as compared to the tilling unit equipped with a reversible plough. On a scale of the working shift time balance, this time increase is negligible.

5. Taking into account that the scientifically grounded standards of modern soil management stipulate ploughing once in several years and reversible ploughs cost considerably (several times) more than conventional ploughs, the wide use of reversible ploughs is not technically or economically advisable.

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