The effect of the land shape on the energy intensity of operation steps

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ABSTRACT: The goal of the work is to find and describe the effect of the shape and size of the land on the energy intensity of an agricultural operation. This effect is expressed by means of coefficient K_S that is determined by a theoretical calculation; the correctness of the algorithm is confirmed by coefficient K_{SP} determined by a field-laboratory measurement. Both coefficients are determined for seven different lands and the results are compared mutually. The results are also indicated for the calculation of fuel consumption and machine performance with respect to the land size and shape. With the help of these relations, a graph was set up for the dependence of the performance (ha/h) and consumption (l/ha), (l/h) on the K_S coefficient during ploughing.

Keywords: energy intensity; fuel consumption; land size; land shape

In the second half of the past century, technological progress changed dramatically the performance of agricultural machines. The consequences were both positive and negative. The positive aspect is the stable and abundant production of food, the negative aspect is a larger dependence on fossil fuels and a lower energy efficiency (Giampietro, Pimentel 1994). The consumption of fuels is the main part of all the consumed energy not only during crop production, but also in the entire agriculture sector. In the past time, the consumption of fossil fuels and energy ranks among the most closely monitored issues all over the world. The reason is that the economical development of each country depends to a certain degree on the level of fuel and power resources, the ability of continuous supplying, when these energy resources are limited and can only be obtained with increasing difficulties. The increasing disproportion between energy consumption and the possibility of its providing makes a current issue from the necessity to rationalize all forms of energy use. The solution of the problem of the rationalization of the diesel fuel consumption during crop production is the main part of the rationalization of the consumption of all the energy of an agricultural plant (Ondřej 1985).

Depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16 percent to over 45 percent of the total machine costs (Siemens, Bowers 1999). The maximization of the engine fuel efficiency, maximization of the efficiency of the traction mechanism and the selection of the optimum working speed of the traction set (GRISSO et al. 1999) effects the efficiency of tractors. Apart from the construction parameters of the engine used, the fuel consumption per hour depends on the degree of the use of the engine output and the fraction of the running time with respect to the overall operational time (Pastorek et al. 2002). The energy intensity of individual operations depends not only on the technical parameters of the machine set used, method, depth and intensity of work, the manner of using the machine set, but depends to a considerable extent also on the variability of the physical and mechanical properties of the processed material, land size, its regularity, slope, fraction conditions and other parameters.

In the Research Institute of Agricultural Engineering in Prague, the effect of the factors was analyzed that influence the implementation of operational steps, considered primarily from the point of achieved performances, rated energy consumption, primarily of diesel fuel and the unit direct costs. It is obvious that the greatest influence on performing operational steps from the point of view of exploitation, economical and energy criteria has the size and shape of land units (Syrový et al. 2002). This influence is caused by the number of turns at the headland, when the operational capacity of the machine is not used. During agricultural operations, the headland pattern method of the set motion is the most frequently used, where the operational runs are carried out by the direct motion along one side of the field. The following basic motion patterns of the tractor sets on the land can be included among the headland pattern methods: 1. Shuttle motion pattern; 2. The "casting" and "gathering" pattern of motion; 3. Motion with overlap.

The goal of this paper is to find and describe the effect of the shape and size of the land on the energy intensity of an agricultural operation during various patterns of the set motion.

METHODOLOGY

The description of the effect of the shape and size of land on the energy intensity by the K_S coefficient is carried out with a theoretical calculation that is also verified with a field-laboratory measurement. These calculations are compared with the theoretical calculation of the K_o turning coefficient.

1. Calculation of the coefficients for expressing the effect of the size and shape of the land unit on the energy intensity

(a) With a theoretical calculation:

With the help of the K_S coefficient, we express the effect of the shape of the land on the consumption; this coefficient defines the ratio between the actually cultivated area S and the theoretical area S_T. The theoretically cultivated area S_T is that area which the machine would have cultivated when running the same path as when cultivating the S land without interrupting the work by turning on the headlands.

We determine the coefficient K_S of the ratio of the areas by the relation:

$$K_S = \frac{S}{S_T} \quad (-) \qquad (1)$$

where: K_S – the coefficient of the ratio of the areas (–),
S – actually cultivated area (ha),
S_T – theoretically cultivated area (ha).

The magnitude of the theoretically cultivated area is determined from the relation:

$$S_T = S + l_X(b_{\max} - z \times \varepsilon)\,10^{-4} \quad \text{(ha)} \qquad (2)$$

where: l_X – the run path at the headland with one turn (m),
z – engaging movement of the machine (m),
b_{max} – the largest dimension of the land perpendicular to the direction of the run (m),
ε – coefficient of the use of the machine engagement (–).

After substituting from equation (2) into equation (1) and after rearranging the equations, we obtain the relation for the calculation of K_S:

$$K_S = \frac{S}{S + l_X(b_{\max} - z \times \varepsilon)\,10^{-4}} \quad (-) \qquad (3)$$

We calculate the length of a nonworking run, l_X, during one turn:
1. Open loop turn (Ondřej 1985): $l_X = 6R + 2e$
2. Closed loop turn (Ondřej 1985): $l_X = 8.4R + 2e$

where: R – radius of turning the tractor set (m),
e – cinematic length of the set (the distance between the cinematic centre of the set and the working aggregates of the main machines) (m) (Ondřej 1985).

For more complicated patterns of the motion of the set, we use the following relation:

$$K_S = \frac{S}{S + S_X \times j \times z \times 10^{-4}} \quad (-) \qquad (4)$$

where: S_X – the length of the non-working runs (m),
j – number of patches (–).

For the determination of S_X during the motion of the set with overlap, we use the relation (Ondřej 1985):

$$S_X = \frac{C}{\tilde{}}(1.14R + 0.5C + 2e) - 0.5C + z \quad \text{(m)} \qquad (5)$$

where: C – the patch width (m).

For the determination of S_X during the casting or gathering motion pattern of the tractor set, we use the relation (Ondřej 1985):

$$S_X = \frac{0.5C^2 + C(R + 2e) + 8R^2}{z} + L + 2C \quad \text{(m)} \qquad (6)$$

where: L – the length of one working run (m).

(b) With the field-laboratory measurement:

Data were measured with the help of the GPS35 LV-HVS system with the data recorder and then evaluated in the Topol 6.008 geographical system. The operational speed, geographical coordinates and time were recorded. Apart from the GPS data, the diesel fuel consumption, measured with the EDM 1404 flow meter, was recorded. As a working operation, ploughing was chosen, carried out with the NEW HOLLAND 8770 set with the LEMKEN VARI-DIAMANT 10 7L100 plough. The measurement was carried out at the Rosovice Agricultural Cooperative from 15 July 2004 until 28 July 2004. Ploughing conditions: dry, loamy soil, lowland.

The magnitude of the theoretically processed area, S_{TP}, is determined from the relation:

$$S_{TP} = \nu \times t \times z \times \varepsilon \times 10^{-4} \quad \text{(ha)} \quad (7)$$

where: ν – the average working speed (km/h),
z – engaging movement of the machine (m),
t – overall time necessary for cultivating area S (h),
S_{TP} – theoretically cultivated area determined by the field-laboratory measurement (ha).

The coefficient of the ratio of the areas, K_{SP}, determined with the help of the field-laboratory measurements, is calculated according to the relation:

$$K_{SP} = \frac{S}{S_{TP}} \quad (–) \quad (8)$$

where: K_{SP} – coefficient of the ratio of the areas determined with the help of the field-laboratory measurements (–).

From the database of the measured values, the average speed of the motion of the tractor set, ν, and the total time of cultivating the land, *t*, was determined. In the Topol 6.008 geographical system, the actually cultivated area S and the machine engagement *z* was measured. Area S_{TP} was calculated by substituting these values into relation (7). The coefficient of the ratio of the areas, K_{SP}, was determined by substituting relation (7) into relation (8).

(c) By the theoretical calculation of the coefficient of turning, K_o (Pastorek 2002):

Coefficient K_o, expressing the effect of turning at the headland, is determined according to the relation:

$$K_o = \frac{b \times l \times \varepsilon}{b \times l + 10^3 T_o \times v\,(b - z \times \varepsilon_B)} \quad (–) \quad (9)$$

where: ε – coefficient of the use of the machine engagement (–),
l – land length (m),
b – land width (m),
T_o – time of turning the tractor set at the headland (h),
ν – working speed (km/h).

For controlling the correctness of the theoretical calculation, seven lands of various sizes and shapes were selected. Example of trajectory of movement of the machines is on Fig. 1, and the results are indicated in Table 1.

2. Calculation of the diesel fuel consumption in dependence on the shape and size of the land

The magnitude of the diesel fuel consumption can be calculated with the help of the K_S coefficient. For the determination of the diesel fuel consumption in dependence on the shape and size of the land, we use the following relations:

For the calculation of the diesel fuel consumption per hectare for different shapes of land:

$$Q_{l/ha} = 10(Q_0 + (1 - K_S) \times Q_N) \times z^{-1} \quad \text{(l/ha)} \quad (10)$$

where: Q_0 – fuel consumption during ploughing (l/km),
Q_N – fuel consumption when turning at the headland (l/km).

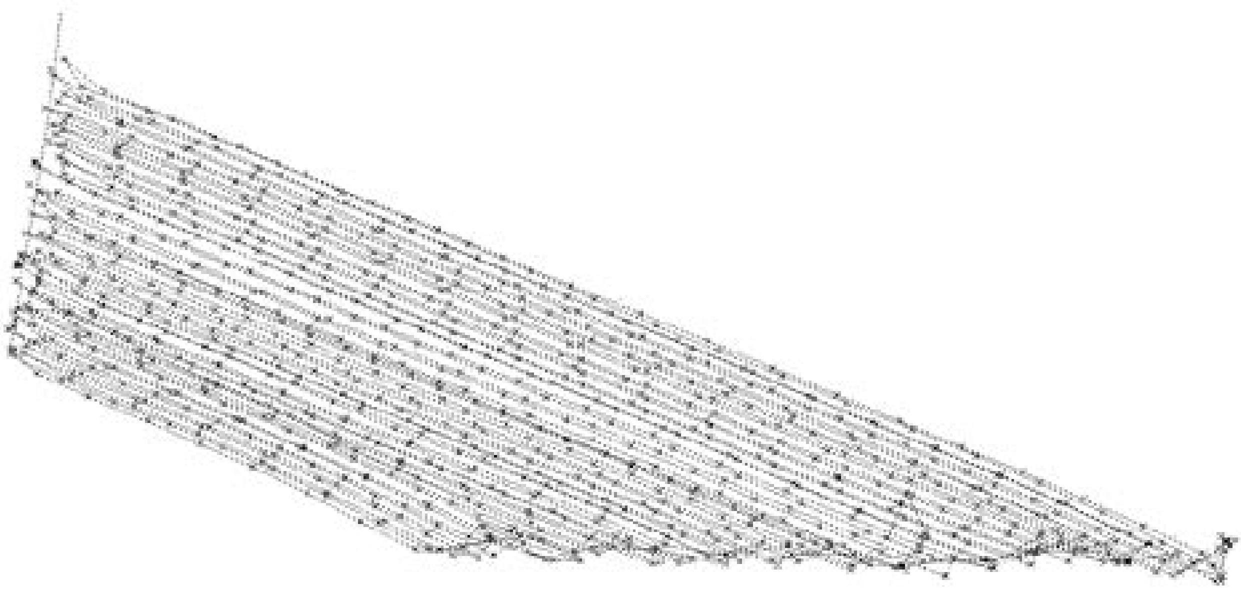

Fig. 1. Trajectory of movement of the machine on the land No. 7

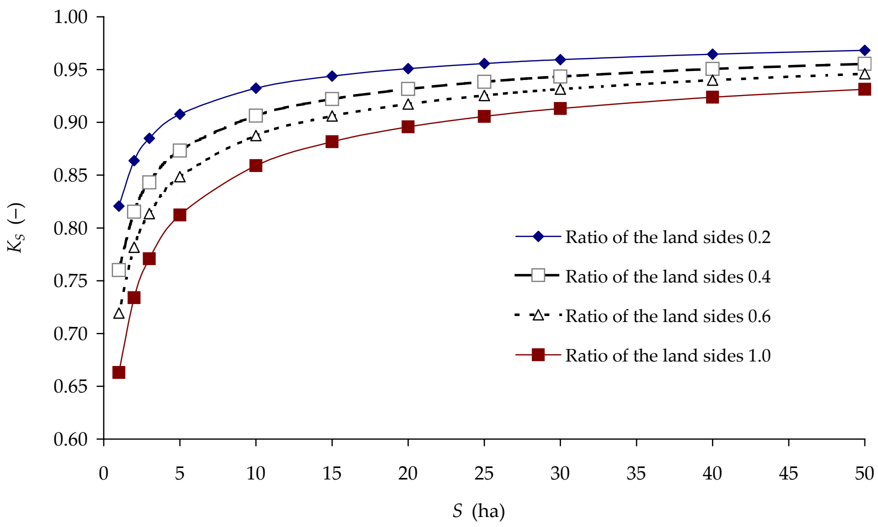

Fig. 2. The dependence of the magnitude of the K_S coefficient on the land area during various ratios of the land sides (land width/land length)

For the calculation of the efficiency for different shapes of land:

$$Q_{l/h} = K_S \times v_0 \times Q_o + (1 - K_S) \times v_N \times Q_N \times Q_N \quad \text{(l/h)} \quad (11)$$

where: v_0 – average speed during ploughing (km/h),
v_N – average speed when turning at the headland (km/h).

For the calculation of the performance for different shapes of land:

$$W = 0.1 \times v_o \times z \times K_S \quad \text{(ha/h)} \quad (12)$$

By using relation (10) for the consumption per hectare, relation (11) for the consumption per hour and relation (12) for the performance, we determine the actual consumption in dependence on the site and shape of the land. The values for the rated fuel consumption during ploughing, v_N, the rated fuel consumption during turning at the headland, Q_N, the average speed during ploughing, v_o, and the average speed when turning at the headland, v_N, were determined by the field-laboratory measurement at ZD Rosovice on 17 July 2004. Measuring conditions: ploughing depth 21 cm, shuttle motion patter, loamy soil, flat terrain, moist soil, temperature 13°C. The results are indicated in Figs. 2 and 3.

RESULTS AND DISCUSSION

In Table 1, the values of coefficient K_S are given that were determined by the theoretical calculation and the field-laboratory measurement using the procedure indicated in the methodology part of this paper. The coefficient of turning K_o cannot be determined unambiguously for more complicated shapes of land. During the calculation of coefficient K_o, the 0.006 h turning time T_o was determined. Engaging movement of the machine 3 m. The speed of the tractor set motion was measured. The radius of turning the tractor set was 5.2 m and the cinematic length of the set was 12 m.

Lands number 2 and 3 have similar shape (ratio of sides). The difference in the result of the K_S coef-

Table 1. Comparison of the coefficients assessing the land shape

Land No.	1	2	3	4	5	6	7
Date	15.7.	21.7.	21.7.	22.7.	22.8.	23.8.	24.8.
Working speed	6.9	7.2	7.2	7.1	7.9	7.8	7.3
Area (ha)	4.75	4.25	1.12	5.00	10.00	10.00	10.38
Land length (m)	954	364	198	428	746	707	537
Land width (m)	47	105	48	110	136	145	188
K_S	0.95	0.88	0.82	0.89	0.93	0.93	0.91
K_O	0.96	0.90	0.83	0.91	0.94	0.94	0.93
K_P	0.92	0.87	0.81	0.89	0.93	0.93	0.92

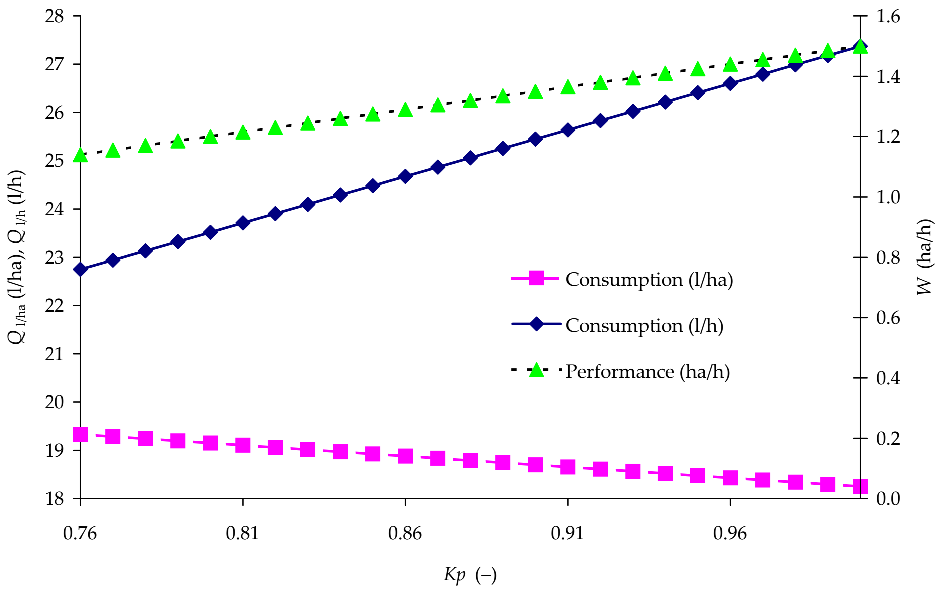

Fig. 3. The dependence of performance W and consumption $Q_{l/ha}$, $Q_{l/h}$ on the K_p coefficient, when ploughing with the NEW HOLLAND 8770 tractor set with the LEMKEN VARI-DIAMANT 10 7 L100 plough

ficient shows on the effect of the land size. Lands number 1 and 4 have almost the same size. In this case, the difference of coefficients K_S is caused by the different shape of the land. The coefficient of engagement 1 was used during ploughing.

The gradual reduction of the effect of the land shape on the K_S coefficient with the increasing size of the land is obvious from the Fig. 2.

The increase of the performance and consumption per hour with the increasing coefficient K_S is caused by the higher exploitation of the working capacity of the machine. The diesel fuel consumption per hectare decreases with the increasing coefficient K_S due to the increasing length of the path ran on the headland. The fuel consumption per hour decreases linearly with the decrease of the K_S coefficient due to the increase of the path ran during turning at the headland. It is obvious that the effect of the land shape on the fuel consumption is small for an area above 25 hectares, because here the maximum difference of the K_S coefficients is 0.06, which corresponds to a difference in the fuel consumption of 0.27 l/ha according to Fig. 3.

CONCLUSION

The results of the theoretical calculation differ only negligibly from the results of the field-laboratory measurement. The results are almost identical for more complicated shapes of lands. The gradual reduction of the effect of the land shape on the K_S coefficient with the increasing size of the land is obvious from comparing the graphs in Figs. 2 and 3.

The effect of the land shape on the fuel consumption is negligible for an area above 25 hectares.

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Vliv tvaru pozemku na energetickou náročnost pracovních operací

ABSTRAKT: Cílem práce bylo zjistit a popsat vliv tvaru a velikosti pozemku na energetickou náročnost zemědělské operace. Tento vliv je vyjádřen pomocí koeficientu K_S, který je určen teoretickým výpočtem a správnost algoritmu výpočtu je potvrzena pomocí koeficientu K_{SP}, určeného polně-laboratorním měřením. Oba koeficienty jsou zjištěny pro sedm různých pozemků a výsledky jsou vzájemně porovnány. Dále jsou uvedeny vztahy pro výpočet spotřeby paliva a výkonnosti stroje s ohledem na velikost a tvar pozemku. Pomocí těchto vztahů je sestaven graf závislosti výkonnosti (ha/h) a spotřeby (l/ha), (l/h) na koeficientu K_S při orbě.

Klíčová slova: energetická náročnost; spotřeba paliva; velikost pozemku; tvar pozemku

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