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Translocation of the upper soil layer in multiple operations of seedbed preparation

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Abstract

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Translocation of tracers incorporated into the upper layer of topsoil was evaluated in the course of seedbed preparation for winter wheat. Aluminium cubes with the edge length of 16 mm were used as tracers that were placed into the soil before its tillage into furrows perpendicular to the direction of passes. After the passes of the OPALL-AGRI combined cultivator, the tracers were searched and marked using a metal detector. The translocation of tracers was evaluated during multiple passes on flatland and on the slope. During the seedbed preparation on the slope, downslope and upslope passes in a fall line direction were chosen. Results of the tracers movement measuring that simulate the soil particle translocation indicate a pronounced movement of the upper layer of topsoil during multiple downslope passes of the combined cultivator. A significant translocation was also observed after passes on flatland. A significantly smaller lengthwise translocation of tracers was found out at upslope passes. The type of translocation on flatland and upslope was quite similar, on the other hand, downslope movement was much larger. The upslope passes were found to have a very limited function with regard to the correction of the undesirable downslope movement of soil particles that occurs in the course of tillage.

Keywords: tillage erosion; metallic tracers; multiple tillage operations

The principle of soil erosion is disturbance of surface soil layers, transport of soil particles and their sedimentation and accumulation at other places. Agricultural soils are exposed to harmful effects of water and wind erosion. These types of erosion processes have been studied in detail for a long time. Janeček et al. (2012) stated that in the territory of the Czech Republic almost 50% and 10% of arable land area were threatened by water and wind erosion, respectively. The criteria for assessing of soil erosion are increasing. The Situation and Outlook Report of Soil for 2015 indicates a potential threat to water erosion of 67% and wind erosion of 18% in the Czech Republic.

Relatively little attention has recently been paid to tillage related erosion. However, the downslope translocation of soil particles as a result of soil tillage performed every year is a serious degradation factor affecting the soil in broken terrain. A large stimulus to study tillage erosion was given by the Govers' investigations (Govers et al. 1999). Van Muysen et al. (2002) also accentuated that tillage erosion was a crucial problem. Other sources documented that in broken terrain in the conditions of the Western Europe, tillage erosion might exceed by its intensity the harmful effects of water erosion. Blanco–Canqui and Lal (2008) reported for such conditions the downslope translocation of 15 to 60 t/ha/year of soil. Van Oost et al. (2006) also demonstrated that in the long run, soil losses due to erosion caused by tillage every year could be higher than soil losses incurred by erosion caused by surface runoff.

In the last years, interest in the study of tillage erosion has been gradually increasing. Nevertheless, there is a lack of recorded data and evaluated

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results documenting the effect of particular implements on soil particle translocation during tillage. The lack of results also applies to an assessment of the influence of various tillage methods and sowing operations on translocation of the upper layer of topsoil. Li et al. (2007) summarized that in general there was considerably more information about the effects of primary tillage on soil particle translocation than of secondary tillage. The soil particle translocation by mouldboard tillage was studied relatively in great detail (Van Muysen et al. 2002). Slope gradient, tillage depth, tillage speed and tillage direction in sloping fields are of crucial importance for soil particle translocation.

Wang et al. (2016) accentuated that the processes of water erosion and tillage erosion are usually studied separately, these processes are however interrelated. The every-year movement of soil particles is typical of tillage erosion that results in the gradual downslope displacement of the upper part of topsoil and its accumulation in the lower part of fields. Interactions between water erosion and tillage erosion were identified for the first time by Lobb and Kachanoski (1995).

In the downslope passes of the implements along the fall line the movement of soil particles differs in relation to the slope shape. If the slope gradient is invariable, the downslope translocated soil by the implement is replaced by the soil from the slope part above this place. The situation is different if the slope gradient is variable (Govers et al. 1999). On a convex slope its gradient increases, which increases the soil translocation. In this part of the slope more soil is carried away than is received from the upper part. On the contrary, the soil is accumulated in the concave part of the slope, and more soil is transported there than it is carried away.

To measure the translocation of soil particles, tillage tracers are used that are incorporated into the soil into furrows oriented perpendicularly to a direction of the subsequent passes of tillage implements. A list of tracers used by various authors was published by Logsdon (2013). Aluminium (Al) cubes of the edge length less than 15 mm were used the most frequently while iron tracers or metallic tracers are searched by a metal detector. Other used material is crushed rock of the colour contrasting with the soil colour – usually limestone grit. When testing tracers of different sizes, Van Muysen et al. (2006) found out that differences in their size were not significant. To measure the translocation of soil particles, other types of tracers were also tested, e.g. radioisotope ^{134}Cs (Quine et al. 1999).

MATERIAL AND METHODS

Measurements of soil particle translocation were done after winter rape harvest, subsequent ploughing and levelling of the soil surface by drag and harrows. Both operations were performed two weeks before measurements in order to allow for the natural subsidence of soil. The objective of measurements was to evaluate the effect of the operation of seedbed preparation performed by an implement with non-powered working tools on the translocation of soil particles on flat land and on slope after multiple passes of the same implement. The chosen operation is typical secondary tillage using a combined cultivator that levels the soil surface, performs shallow loosening of soil to the sowing depth of a subsequent crop, crumbles soil lumps and prepares the seedbed, for winter cereal in this case.

A combined cultivator (working width of 6 m; OPall-AGRI s.r.o., Czech Republic;) pulled by a tractor with the engine power of 118 kW was used for seedbed preparation. Operating speed of the combined cultivator during seedbed preparation was 4.5 km/h in all operations.

Basic information on the field selected for measurements is as follows:

Altitude was 460 m a.s.l. Soil was sandy-loam Cambisol with the content of particles smaller than 0.01 mm in the topsoil layer of 21.3% by weight. The content of oxidizable carbon in topsoil was 2.3%. Average moisture content of soil at a depth of its tillage at the time of measurement was 7.3% by volume. Basic properties of soil were determined by the analysis of soil samples in a laboratory of the Research Institute for Soil and Water Conservation (RISWC). A Theta probe (Delta Devices, United Kingdom) was used for soil moisture measurement. Slope gradient of the field at places of measurement were 0.9° (flatland), 8.1° (upslope passes), 9.8° (downslope passes). Basic physical properties of soil are shown in Table 1. Physical properties of soil were determined by

Table 1. Soil properties before secondary soil tillage

Depth (m)	Bulk density (g/cm^3)	Porosity (% vol.)
0.05–0.10	1.33	49.2
0.10–0.15	1.36	48.1

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the method of undisturbed soil samples (Kopecky cylinders of 100 cm^3 in volume, 9 repeats in each depth) and by subsequent processing in a laboratory of the Czech University of Life Sciences. The values in Table 1 document soil loosened after preceding ploughing with a high proportion of macropores. The soil physical properties are typical of soil shortly after ploughing (Novák et al. 2011).

Before soil tillage by a combined cultivator, metallic tracers (aluminium cubes with the edge length of 16 mm) were incorporated to a depth of 0.05 m into furrows perpendicular to the direction of the passes of this implement. For each variant, 30 tracers distributed by 0.033 m were used. The spatial distribution of these tracers was determined after each operation using a metal detector M6 (White's Electronics, USA) and marked on the soil surface. The localization of tracer positions in a rectangular system was done. The maximum depth of tracers was 0.1 m (not monitored for this paper). Translocation was evaluated in relation to the initial known position. Data were subsequently processed by Microsoft Excel software (MS Corp., USA) and Statistica 12 programme (Statsoft Inc., USA).

RESULTS AND DISCUSSION

Fig. 1 represents the translocation of tracers in multiple passes of an OPaLL-AGRI combined cultivator on flatland. The graph shows that in multiple passes of the implement at the same direction the tracers were gradually translocated in a direction of the cultivator movement. In the graph the posi-

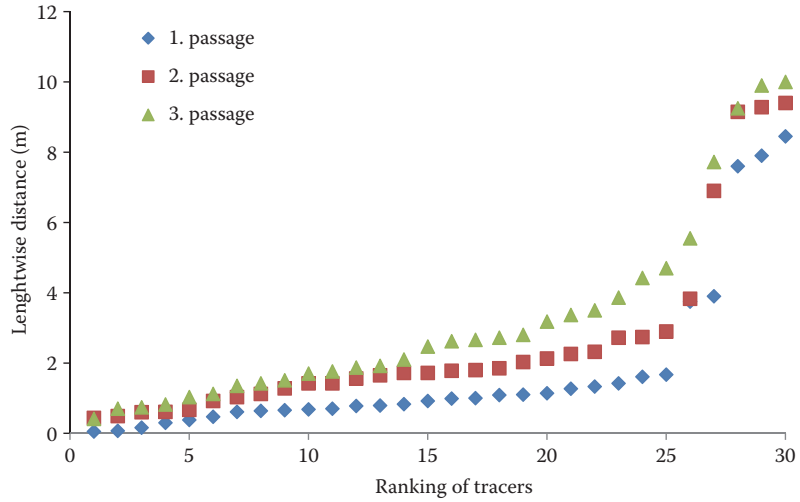

Fig. 1. Ranking of tracers for multiple passes on flatland

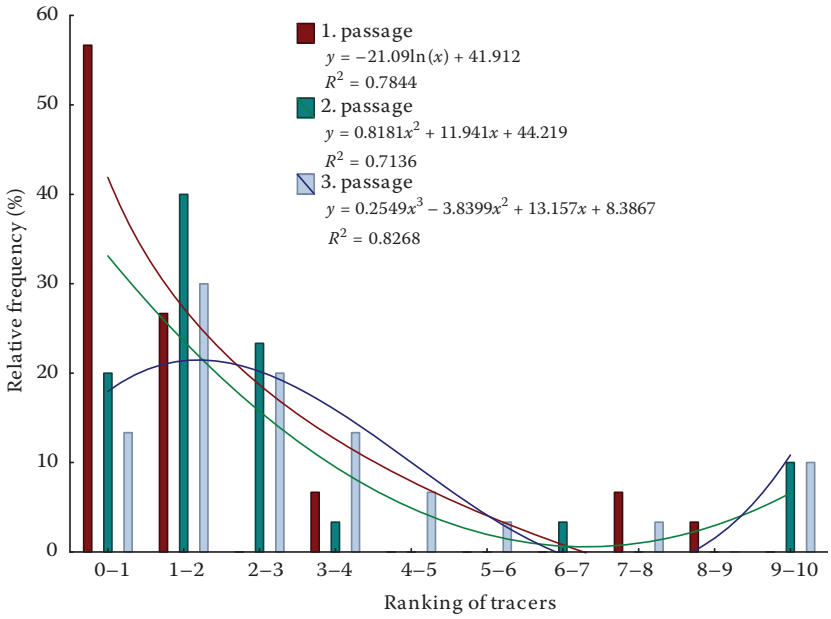

Fig. 2. Relative frequency for multiple passes per 1 m (flatland)

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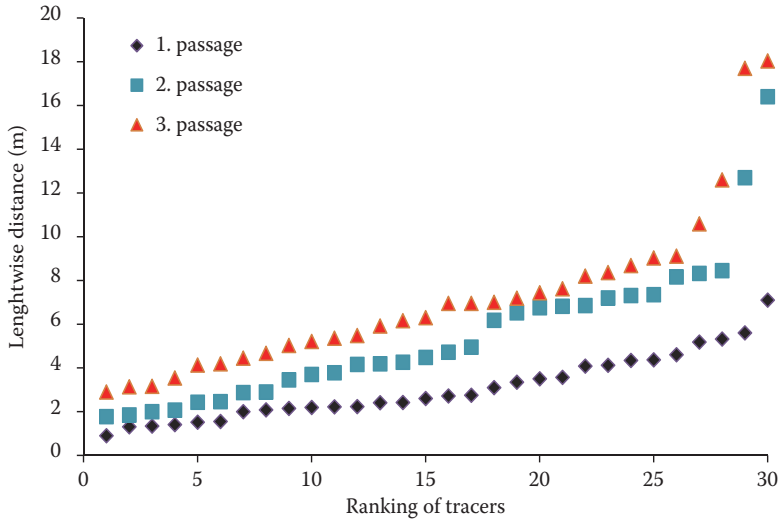

Fig. 3. Ranking of tracers for multiple passes down the slope

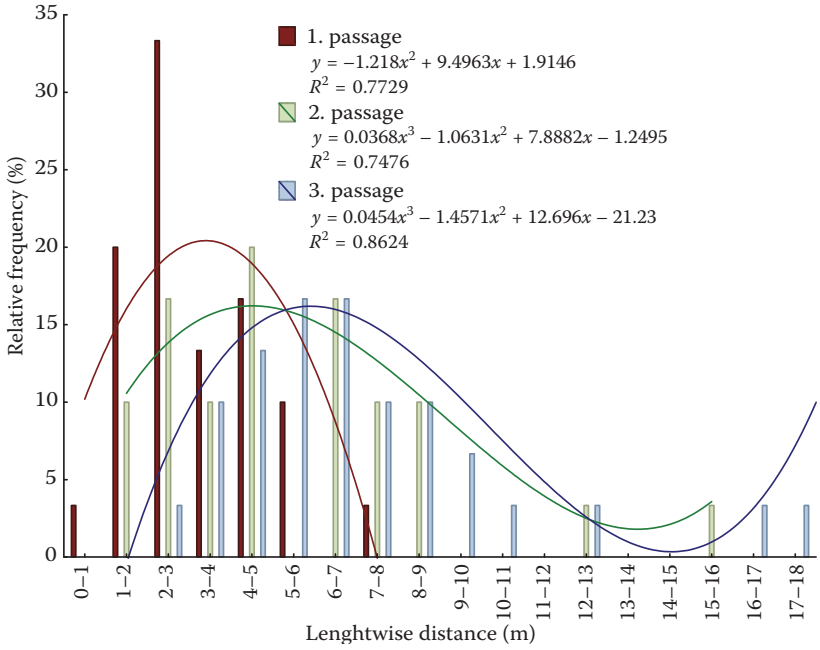

Fig. 4. Relative frequency for multiple passes per 1 m (down the slope)

tion of all individual tracers is expressed. The graph shows that the majority of tracers moved a small distance. Several tracers were however moved to a much larger distance. This is probably caused by moving residues of the previous crop. Displacement characteristics did not change significantly even at the repeat of passes.

Relative frequency of tracers in segments of the tracer distance from the initial location in the soil is expressed by trend curves in Fig. 2. The curves clearly illustrate the gradual translocation of tracers in a direction of the cultivator movement during multiple passes. This movement can be also described using mathematical functions. The character of displacement is quite complex and is strongly influenced by working tools of a cultivator. Outermost tracers were displaced due to the carry of plant residues by tines.

Fig. 3 documents the translocation of tracers in multiple passes of the combined cultivator down the slope of 9.8° gradient. The graph illustrates the translocation of tracers in a direction of the fall line. The trend curves in Fig. 4 express the shape of the gradual translocation of tracers that simulate the movement of soil particles. From this graph, it is possible to derive a significant downhill movement of the surface layer of topsoil caused by the working tools of the combined cultivator and due to gravity. Displacement is far more massive than in the case passes on the flatland. Cultivator tines tend to move the whole of the surface layer of soil

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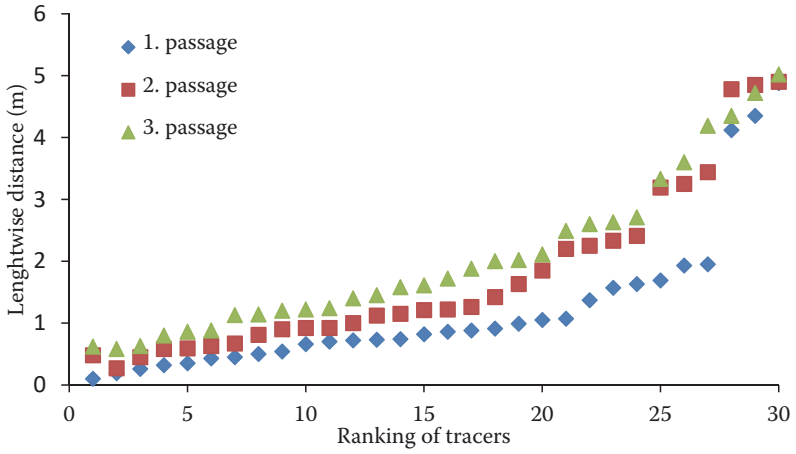

Fig. 5. Ranking of tracers for multiple passes upslope

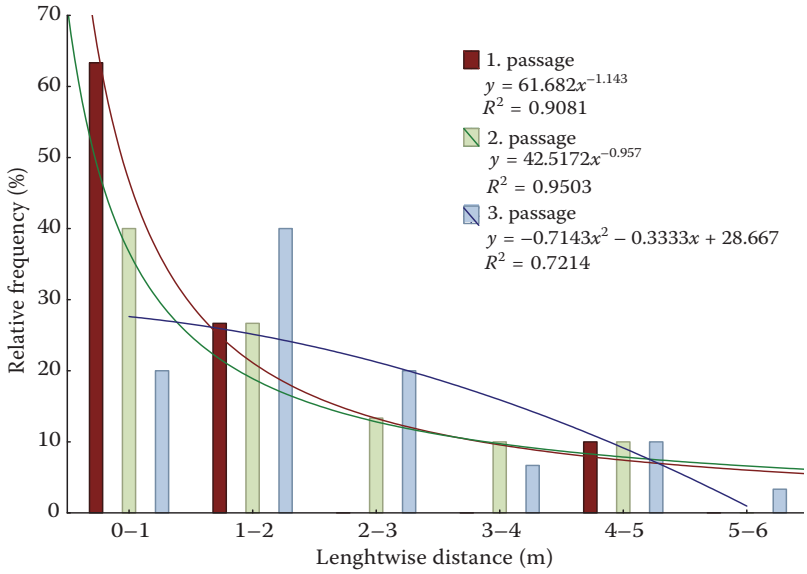

Fig. 6. Relative frequency for multiple passes per 1 m (upslope)

in the direction of movement. This phenomenon is moreover strongly influences by organic matter in the surface and subsurface layers. Tracers were moved to a distance of more than 17 meters. Again, displacement of particles can be described using regression models, however, these results cannot be generalized. Logsdon (2013) found out that surface-applied tracers were moved down the slope to the distance greater than 3 m, and upslope to nearly 2 m distance. Other measurements showed that after conventional tillage most distant particles were found more than 3 m from their original location in the topsoil. The reduced tillage technology translocated soil particles to the distance a little over 1.5 m (Hůla, Novák 2016). Still, it can be stated that the move is more pronounced in the direction of the fall line and affects cultivation, especially on slopes.

Upslope passes of the implement during soil tillage could be considered as a corrective measure to the impacts of downslope passes and also to the impacts of soil water erosion. The graphical representation of tracer translocation in Figs 5 and 6 show that tracers were moved upslope to a substantially shorter distance than when the implement passed on flatland and down the slope. Also, the representation of tracers in length segments in a direction of tillage passes, expressed by trend curves, indicates a considerably smaller translocation of tracers in a direction of passes than in preceding cases. As seen from the graphs, displacement of particles up the slope is not able to compensate displacement in the direction of the fall line. Displacement values are surprisingly similar to those when the machine moves on flatland.

A different view on the results of tracer translocation is given in Figs 7 and 8. The graphs show trend curves expressing the movement of tracers after the third travel of the combine cultivator at differ-

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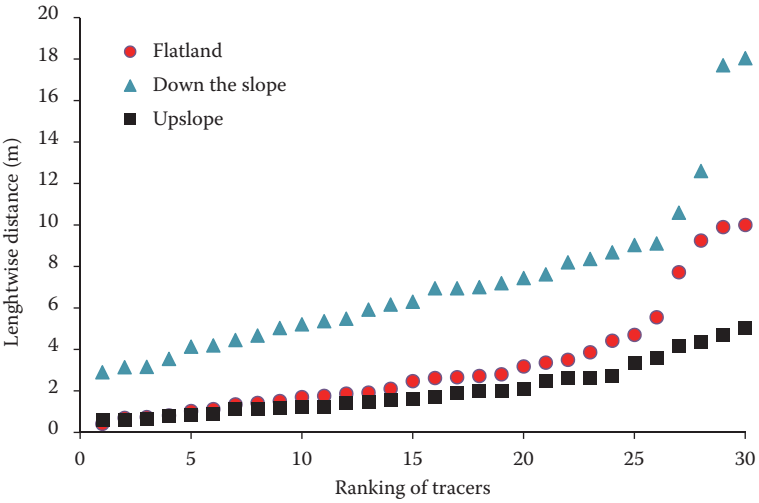

Fig. 7. Ranking of tracers for all variants after 3 passes

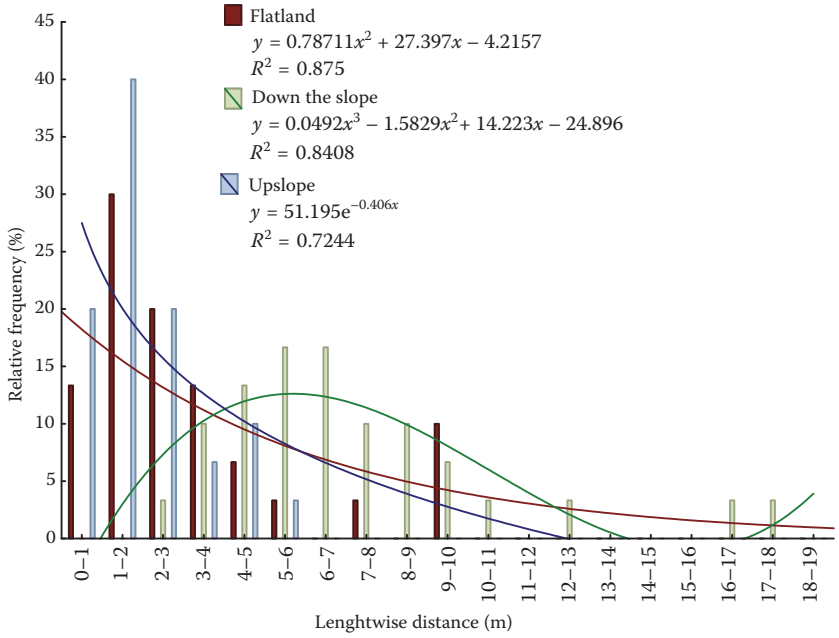

Fig. 8. Relative frequency for three passes per 1 m (all variants)

ent parts of the field when travelling on flatland, downslope and upslope. It is to accentuate again that there is a cardinal difference in the translocation of the upper layer of topsoil in the course of downslope passes compared to upslope passes and when the implement goes on flatland. The upslope passes of this implement cannot be understood as a correction of the undesirable downslope translocation of these particles.

The results of evaluation of tracer translocation in seedbed preparation by the combined cultivator indicate a surprisingly pronounced movement of the upper layer of topsoil by this implement with non-powered working tools when going downslope in a fall line direction and when going on flatland. This is consistent with the results reported by Blanco–Canqui and Lal (2008) about negative impacts of tillage erosion. The results also support arguments that in certain soil conditions damage caused by tillage erosion can be greater than soil losses caused by water erosion (Van Oost et al. 2006). The results of measurements of tracer translocation by the combined cultivator may extend information in the area accentuated by Li et al. (2007) – the lack of data on the soil particles translocation by implements during secondary tillage (seedbed preparation) in comparison with the results of measurements in primary soil tillage.

CONCLUSION

The results of measuring the translocation of tracers placed into the soil before secondary tillage

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indicated a pronounced effect of seedbed preparation by the combined cultivator with non-powered working tools on the movement of the upper part of topsoil in a direction of passes on flatland and down the slope. The upslope passes of this implement cannot be understood as the complete correction of the undesirable downslope translocation of these particles. The results of measurements also demonstrate the need of reducing the seedbed preparation intensity in sloping fields. Multiple operations of seedbed preparation on sloping lands are connected with the undesirable downslope movement of the upper part of topsoil in a fall line direction. Hence, soil tillage on sloping lands can have negative impacts due to its secondary effects, similarly like water erosion of soil.

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