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PAPER REVIEWS

RIDGED TERRACES – FUNCTIONS, CONSTRUCTION AND USE

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Abstract. Erosion is considered one of the basic processes, leading to soil degradation and contamination of surface water. Terracing is a technical soil conservation method, generally intended to control surface runoff and soil losses. Ridged terraces are mainly used to control soil erosion but they could also be used as a mean for harvesting of rain water. These terraces divide the slope into smaller hydrographic units, significantly reducing the rout of the runoff, thus affecting water circulation on the slope and in the entire basin. Water, retained by terraces, does not participate in the direct precipitation-runoff transformation process. As, a result, water resources in a given site are increased. In Poland there is no tradition and experience with the use of ridged terraces, especially as a measure for rain water collecting. This paper describes types of ridged terraces, their functions and typical cross-sections, as well as methods of calculation of ridged terraces spacing.

Keywords: terraces, contour banks, surface runoff, erosion.

1. Introduction

Soil erosion is considered one of the basic processes leading to soil degradation and contamination of surface water. Over the last decade, the importance of soil protection has been emphasised many times in the documents of both, European and world-wide relevance. A number of declarations, pertaining to soil protection, were adopted during the Earth Summit in Rio de Janeiro in 1992. The deterioration of soil quality in the countries of Central and Eastern Europe manifested by increased erosion was presented in the SOVEUR Report (Van Lynden 2000). In the research programmes, supported by the European Union, much attention is being given to the research pertaining to soil protection against erosion and contamination. Both, the European Union Strategy for Sustainable Development (2001) and the European Charter for the Protection and Sustainable Management of Soil (2003), emphasise the hazards to agroecosystems sustainability due to the loss of soil fertility and soil erosion (COM 2002; Wischmeier and Smith 1978).

Although this process has been considered of great importance for the natural environment, determination of the size of the damage caused by soil erosion still creates many problems. They are connected with the difficulty in describing complex physical processes such as infiltration, surface runoff, soil surface crust formation and erosion (particle separation, transfer and sedimentation) simultaneously occurring on the soil surface during precipitation. Changes in the intensity of these phenomena are linked with the change in the intensity of precipitation, intensity of water runoff and with the conditions prevailing on the soil surface and in its subsurface layer – moisture, surface roughness, vegetation, slope, *etc*. These are the factors differentiating the erosion processes that prevail in individual slope fragments and in the entire basin. The detachment of soil particles caused by precipitation waters and their transport by the scattered surface runoff is prevalent on the slope. Concentrations of the surface runoff are a common phenomenon in the entire basin and result in formation of erosion rills and gullies. As a result, water erosion is particularly difficult to forecast and combat (Rejman and Dębicki 2002; Dębicki and Rejman 1990).

2. Functions and constructions of terraces

Terracing is a form of mechanical soil conservation method, generally intended to control erosion and surface runoff. Terraces are constructed to fulfil multiple functions (Natural… 1982), among which the most important are to:

- reduce surface erosion through the shortening of the rout and reducing the speed of the runoff and sediments on the ground surface, increase the surface water retention via storage of precipitation or melt waters,
- reduce the flood hazard,
- increase the groundwater resources due to the infiltration of certain amounts of water stored in the frontal dyke of a terrace,
- decrease the risk of ravine formation.

The history of terraces is very long. According to Schwab (Schwab *et al.* 1996), terraces had been used for thousands of years in many regions of the world. The first terraces used in agriculture were built of large steps or

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horizontal dykes. The bench terraces were most commonly used in Europe, Australia and Asia while in the south of the USA, these were usually ridgeless channel terraces. In the late 18th century these terraces were built across a field slope and had a function of collector trenches. The technological development has brought a wide variety of terrace constructions depending on the needs and functions of agricultural lands.

One of the oldest classifications of terracing was made by Czerkasov (Czerkasow 1950). The classification divides terraces into ridged terraces, bench terraces and transitional varieties (Fig. 1).

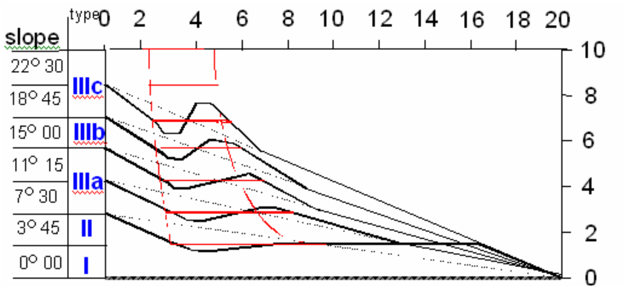

Fig. 1. Classifications of terracing by Czerkasov (1950)

TYPE I. This type of terracing is used on a slope of 0–0.06, where the ground surface is formed with reverse slopes, or horizontal surface and they are often equipped with a ridge. A system of absorptive furrows may also be classified as Type I. Terraces without outflow of Type I, with small ridges on a slope of 0.05–0.10, were formerly used on lighter soils by the Southern United States. The ridges are not high (0.3–0.5 m), their base is c. 1 m and they are made of a small shallow ditch in front of the ridge. Due to the volume of earthworks, this type of terracing is considered to be economical. However, there is a useless area under the ridge, and the ridges themselves can become overgrown by weedy vegetation and are easily washed out, which is a construction drawback of these terraces (Sielnikov 1989).

TYPE II. The terraces of this type are built on slopes of 0.06–0.13. These are ridged terraces with a wide and not very deep trench. They are commonly called Magnum terraces, named after an American farmer who began using them around 1885. The ridge width ranges from 4.5 to 7.5 m, and the ridge height is 0.3–0.6 m. Such terraces are usually 20 to 30 m wide. The ridges should be sown with grass in the first year they are built. Only then they can be used as the other part of the field. The terraces of Type II may also have an outflow. In fact, they are less effective in performance than wide-ridged terraces. Where possible, the longitudinal slope of the terraces with outflow should be the same (for a terrace length of up to 100 m), or it can increase with the terrace length (for a length of 100–450 m).

TYPE III a. This type was used in forestation of the slopes in Uzbekistan (trees were planted on ridges).

TYPE III b. This type of terracing is characterized by a deeper trench and narrower ridge toe. The shape of the trench is not triangular but rectangular (the bottom of the trench is inclined).

TYPE III c. These terraces are constructed in Tashkent. The trenches have a shape of a trapezoid and trees are planted on the slope in front of the soil embankment. The collector trenches are divided into spaces of 20 m, in order to prevent large water outflow in the event of any damage done to the ridge.

The described types of terraces are installed with the assumption that the profile takes advantage of the entire usable width, and that the capacity of collector trenches is equal. Obviously, there is a wide range of variants, e.g. several different types of terraces which can be used on the same slope depending on the amount of retained water.

At present, different countries use different classifications of terracing depending on the adopted criteria (ASAE 1989). Some of them are: arrangement (symmetrical and asymmetrical), shape of the cross-section, dyke slope (inclined and non-inclined), the manner of removing water from the terrace (without outflow, with surface or underground outflows).

Among the numerous existing classifications two basic types of terraces are distinguished, *i.e.* ridged and bench terraces. The bench terraces are built on steep slopes exceeding 10% and mostly used for fruit farming, while building ridged terraces the slopes are completely reconstructed. Changes in slope inclination and the division of a slope into individual terraces entail changes in the conditions of water runoff from the slope.

The ridged terraces are used on arable fields or grassland on the slopes up to approximately 10% height. Thus, their construction is rather simple. Most commonly these are low dykes built across the slope to stop water runoff and the wash out of the soil. Ridged terraces divide the slope into smaller hydrographic units, significantly reducing the rout of the runoff, thus affecting the water circulation on the slope and in the entire basin. Water, retained by terraces, does not participate in the direct precipitation-runoff transformation process. As a result, the flood risk is largely reduced and water resources in a given site are increased. The amount of runoff water, which can be changed by ridged terraces into subsurface runoff or stored in retention devices, largely depends on precipitation characteristics: its amount and intensity. It also depends on the infiltration process varying over time and topography. In the areas with low water resources ridged terraces can be one of the methods of water harvesting (Nasri 2002)]. Water harvesting function of terraces can have a positive impact on water balance – they increase surface retention and recharge aquifers. The reduction of the surface runoff and increase of groundwater resources influence the size of flood waves and discharges into rivers. Ridged terraces also contribute to the improvement of water quality in the rivers, by way of impeding penetration of biogenic compounds (nitrogen and phosphorus) and pesticides from cultivated fields.

Depending on the arrangement of the ridge on the slope, terraces can be classified into two types- with and without outflow (Prochal 1984).

Ridged terraces without outflow (Fig. 2) are formed parallel to the contours. They are built primarily on permeable soils in the areas of relatively low precipitation. The dyke of the terraces without outflow must be in the horizontal position, which is the main precondition of their proper functioning. Water, running from the area between the terraces, is stopped before the dyke.

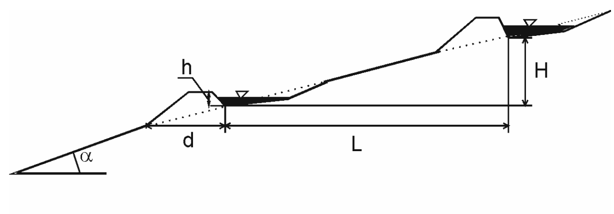

Fig. 2. Ridged terraces without water outflow (where: L, H – horizontal and vertical spacing, respectively)

In the first type terraces, retained water is infiltrated into the ground, thus changing the surface runoff into the subsurface runoff. Eventually, part of water evaporates. The parameters of the terrace are to be selected in a manner that the water inflowing to the dyke does not flow over the top. In practice, this would mean breaking of the embankment and destruction of the dykes located below, *i.e.* the entire anti-erosion system. Overflows in the terraces are to ensure the outflow of waters from torrential rains.

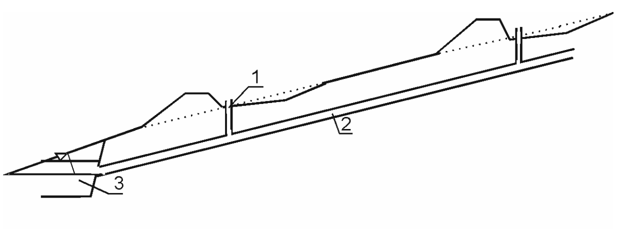

Fig. 3. Ridged terraces with outflow (1 – well, 2 – pipe, 3 – pond)

The terraces can be further classified into terraces with surface and with underground outflow. More modern construction apply to the terraces with underground outflow, where water is drained through wells and underground pipe systems to the lower-laying retention measures, like ditches, rivers or water reservoirs.

Terraces with subsurface outflow (Fig. 3) are constructed to store water in reservoirs by vertical well and subsurface pipe. This type of terrace is constructed in the situation when water in front of the dyke should not stagnate for a longer period of time. Therefore, the ridges of surface outflow terraces are inclined. The type is mainly used in the areas featuring high precipitation level and in soils of low absorption capacity. The dykes in terraces with surface outflow are designed to be slightly inclined towards the retention measures, which usually is a ditch draining water to a water reservoir or to a watercourse. They are designed to carry water through or under embankment to a lower elevation.

Depending on dimensions the majority of terraces are built using bulldozers or other earthwork machinery. Cultivation is started from the ridges. The humus layer is removed first next dykes are formed and finally the humus soil is levelled. The dyke can be formed using collected soil from the top of the slope or from both sides, from the top and from the bottom.

Despite the difficulties in crop farming, the system of terraces was and still is successfully used due to the efficient functioning and relatively low maintenance costs. However, terraces need permanent care because stronger flows can easily destroy them. The level of ridges and longitudinal slope of trenches, running above the dyke, as well as the technical condition of outlets to slope reinforcements should be systematically checked. Large amounts of mud deposits, that are often accumulated in such places, might impede or even prevent the next runoffs.

So far the system of ridged terraces has not been used in Poland, although, some authors such as Nowicki (1977), Mazur (1988) treat so-called ribbon fields as a terraced field system. The few sites in Poland, where ridged terraces are currently used, are the mining soil banks (Bełchatów, Konin, Turów) and mountain forest areas (the Sudeten).

There are critical opinions in the Polish literature (Ziemnicki 1967; Baran, Turski 1997), which negate the purposefulness of the use of ridged terraces on arable land. The authors maintain, that such terraces are too expensive to install and can only be profitable where labour force is cheap, or in the case of expensive and profitable crop production. They also state that, because of small erosion processes, installing ridged terraces in Poland is impractical when compared with the USA where protective treatments on slopes with small inclination are necessary. On the other hand, Dobrzański *et al.* (1953) believe that the advantage of the system is that the arrangement of arable fields should not necessarily be connected with the landscape, but only suit farming conditions.

3. Spacing of ridged terraces

The dimensions of the cross-section of a dyke and dyke spacing are the basic parameters of ridged terraces.

The cross-section of a dyke should have slight sloping so that it is passable for the machines. It has been assumed that the dimensions of a dyke should be (Kostiakow 1965): toe width 1.5–4.0 m, dyke height h equal to 0.2–0.35 m, terrace height equal to 0.6–1.2 m, depending on the slope of a site and the calculation value of rainfall intensity. In the Czech Republic, recommended width of a dyke on permeable soils, on the slopes up to 8% is from 0.8 to 1.5 m and the height is 0.15–0.30 m, whereas on steeper slopes dykes should be 2–4 m wider and 0.25–0.40 m. higher (Holy 1978).

In the areas, where runoff of spring water or torrential rains is highly abundant, it is necessary to raise the height of the dykes and equip them with culverts. The outflow of water from the terraces should also be installed at the end of the dyke. In such areas the longitudinal slope of dykes in the terraces should range from 0.005 to 0.01 to allow water flow along the dyke. In such a case, the width of dykes at the base is greater (from 6 to

9 m) and the dykes are low (from 0.15 to 0.25 m) so that the machine traffic is not obstructed and that the dykes and the entire terrace area can be sown at the same time. The terrain slope along the dyke base should be at such an angle, that the velocity of the runoff along the dyke were lower than the critical velocity resulting from the soil washout. For the terraces with outflow, calculation of parameters of water draining facilities from the terrace is also necessary.

The length of the terrace depends on the field size and character, soil infiltration capacity and possibility of water drainage. The construction of exceptionally long terraces for more efficient farming is advisable, however, this is hazardous in the case of heavy storms, since water might break the dykes in the places of local depressions. Therefore, when designing terraces, their limited length should be taken into consideration. It is acceptable that on permeable soils terraces can be longer than on impermeable ones. Hudson (1981) proposes the maximum lengths of terraces, which in the USA is up to 500 m, whereas in Africa – from 250 m on sandy soils and 400 m on loamy soils.

Spacing ridged terraces, various calculation methods can be used. Generally, they are divided into theoretical and empirical. One of the oldest theoretical methods of calculating ridged terrace spacing was developed by Ramser (1927) (according to Czerkasov (1950), after Ostromęcki (1947)):

$$L = \frac{h}{2\sigma R}\left(\frac{d}{2} + \frac{h}{S}\right), \quad (1)$$

where: h – height of bank [m], R – precipitation [m], s – slope [–], d – width of bank [m], σ – runoff coefficient [–].

This method determines the capacity of a reservoir storing water above the dyke. Its capacity depends on the dyke's height and depth. With the uniform dyke height, the capacity is increasing with the decrease in the slope. The coefficient ranges from 1 (total runoff) to 0 (water retained in the soil, no runoff). Its value depends on soil type, structure, permeability, storage capacity, as well as on forest cover, quantity of arable land and ploughing direction. Besides, soil moisture, duration of precipitation, spring soil defrosting conditions have effect on the runoff coefficient (Kostiakow 1965). Estimated runoff coefficient values differ with individual authors.

In some countries (USA, Africa, Israel, Libya), terrace parameters are selected on the basis of the empirical relationship (Morgan 1986). In the USA they were determined using the following equation (Mazur 1988):

$$H = xs + y, \quad (2)$$

$$L = (xs + y)\,(100/s), \quad (3)$$

where: L – horizontal spacing of terraces [m], H – vertical spacing of terraces [m], s – slope [%].

The x and y coefficients depend on precipitation and soil erosion. The values of coefficients are reliable only for the conditions in which they were determined. Equations for individual countries were defined on the basis of equation 3, 4 (Table).

Equations for individual countries (Natural… 1982)

Land	Formula	Parameters
USA	$H = xS + y$	x – depend on geographical location, y = 1 for erodible condition, y = 2 for resistant soils with good cover, S – average land slope
South Africa	$H = S(x)^{-1} + y$	x – 1,5÷4 (depend on rainfall) y – 1÷3 (depend on erodible conditions)
Israel	$H = xS + y$	x – 0,25÷0,3, y – 1,5÷2,0 (x, y – as above)

Moreover, a well-known Universal Soil Loss Equation (USLE) can be also used to calculate the spacing between ridged terraces (Wischmeier and Smith 1978). The USLE model predicts the average annual soil loss. If the average tolerable soil loss A in a given site is determined, calculation of slope length factor L depends on terrace's spacing

$$L = A\,(RKLSCP)^{-1}, \quad (4)$$

where: A – means annual soil loss [t ha^{-1}year^{-1}], R – rainfall caused erosion index [MJ ha^{-1}mm h^{-1}], K – soil erosion factor [t MJ^{-1}year^{-1}ha^{-1}h mm^{-1}], L – slope length factor [–], S – slope steepness factor [–], C – crop management factor [–], P – erosion control practice factor [–].

Spacing of terraces L [m] is possible to calculate by:

$$L = 22{,}13\, L^{1/a}, \quad (5)$$

where: L – permissible value of slope length factor calculated from equation 4, a – is 0,3 for land steepness 1–3% and 0,5 for slope bigger than 5%.

The described equations for ridged terraces spacing do not bring a clear-cut answer to the question- which of the equations is most applicable in Polish conditions. The research by Baryła (2002) on the arable land of the Agricultural Experimental Station in Puczniew has proved that the spacing between ridged terraces can be calculated by means of mathematical model which, unfortunately, is suitable only for local conditions. The aim of the studies, that are currently being carried out on the plots designated for different farming purposes (grass, wheat, bare fallow), is to determine the spacing between ridged terraces for various climatic conditions.

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KRAIGINĖS TERASOS – FUNKCIJOS, KONSTRUKCIJOS IR NAUDOJIMAS

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S a n t r a u k a

Aprašytos kraiginės terasos, naudojamos kaip priemonė, sauganti dirvožemį nuo erozijos ir leidžianti reguliuoti vandens cirkuliaciją baseine. Pateikta kraiginių terasų konstrukcijų charakteristika. Lenkijoje tokios terasos beveik nenaudojamos, ir viena iš priežasčių – nėra jų projektavimo pagrindų. Tačiau naudoti šias terasas kaip priemonę nuo erozijos Lenkijoje būtina, kadangi jos klimato sąlygomis nesant augalinės dangos tirpstantis sniegas pavasarį ir gausūs krituliai vasaros metu labai veikia dirvožemį. Kraiginės terasos neleidžia vandeniui nutekėti nuo dirvožemio ar miško paklotės ir leidžia daryti įtaką vandens išteklių formavimuisi.

Reikšminiai žodžiai: kraiginės terasos, kontūrų ribos, paviršiaus nuotėkis, vandens erozija.

ГРЕБНЕВЫЕ ТЕРРАСЫ – ФУНКЦИИ, КОНСТРУКЦИИ И ИСПОЛЬЗОВАНИЕ

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Р е з ю м е

Представлено значение гребневых террас как мероприятий, используемых для противоэрозионной защиты почв и управления движением воды в водосборе, а также различные виды террас и их конструкции. Гребневые террасы в Польше практически не используются. Одной из причин этого является отсутствие основ их проектирования. Однако применение гребневых террас в качестве противоэрозионных средств в Польше необходимо в связи с тем, что в ее климатических условиях во время весеннего оттаивания снега и летних проливных дождей при отсутствии растительного покрова земли, особенно пахотные, подвергаются эрозии. Благодаря ограничению стока из сельскохозяйственных и лесных угодий с помощью гребневых террас можно активно влиять на формирование водных ресурсов.

Ключевые слова: гребневые террасы, эрозия почв, поверхностный сток.

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