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Factors Affecting the Wheel Rutting on Rural Roads

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Abstract: In this study, the wheel ruts frequency and dimensions were investigated according to geographical aspects, longitudinal gradient and surfacing layer of rural roads in Denji Kola village, Mazandaran Province, Iran. Ruts were divided into shallow and deep wheel ruts. Results showed that the ruts length and area were significantly affected by longitudinal gradient of rural roads ($p<0.0001$). Ruts length in longitudinal gradient class 8-12% was significantly more than other classes ($p<0.05$). The mean of rut length in this class was 8.19 m. The deep ruts frequency in longitudinal gradient class 0-4% was more than shallow ruts, whereas the number of shallow ruts was more than deep ruts in other classes. The effects of geographical aspect on ruts length ($p<0.0001$), ruts width ($p = 0.0019$) and ruts area ($p<0.0001$) was significant. Although, the ruts width and depth on gravel-grassed surface was more than other surfacing layer, the number of ruts in this surfacing layer was less than bare soil and graveled surfacing layer. Thus, thickness layer of gravel which has been covered by grass is the best mixture for surfacing layer of rural roads.

Key words: Rural road, wheel ruts, longitudinal gradient, aspect, surfacing layer

INTRODUCTION

Rural road construction and networks are vital to regional economic development. The road construction is one of the fast growing man-made projects. Research shows that the least 15%-20% of the land in the world has been affected by road networks (Way *et al*., 2005; Juan *et al*., 2007). The current status of the advanced road network has opened up new possibilities for many people in terms of accessibility. Still this road network and its traffic flows have also produced negative effects on local inhabitants and the surrounding flora and fauna (Jaarsma and Van Dijk, 2002; Parsakhoo *et al*., 2008). Without physical access, rural communities face obstacles in take advantage of crop production. Rural road conditions the development perspectives of agriculture and recreation, as well as some possibilities of agriculture related preservation of scenery and nature (Pauwels and Gulinck, 2000; Cannarella and Piccioni, 2005).

The transportation and mainly road safety is one of important issues for Islamic Republic of Iran's planners. The main reasons of this aims are high degree of urbanization (about 65%), large mountainous land area, the long distances between large cities and its privileged location at the crossroads of international trade routes. Islamic Republic of Iran enjoys a well developed transport network. It has about 81000 km of main and regional roads (95% paved), 7,265 km of railway lines, four main ports on the Persian Gulf and three on the Caspian Sea and seven international airports (Zekavat, 2006). The total length of rural roads in Iran is 86200 km. Terrene roads are widely distributed in rural areas of the North of IR-Iran. However, the lack of high level design standards for such roads has led to serious problems in soil and water erosion (Cao *et al*., 2006).

The purpose of road surfaces is to provide a relatively smooth and uniform riding surface with sufficient traction for acceleration and stopping. The surface should be free of defects and function in all weather conditions. Some types of road surface deformation affect only the surface layer. Soil cracking and shallow rutting are limited to the surfacing material and do not penetrate into the base course. Ruts more than 15 cm deep can indicate more serious problems with the base and subgrade and the road surface should be reshaped as soon as possible if it has ruts of between 5 and 12 cm. Five centimeter ruts are easy to see and are sufficiently deep to carry a potentially damaging amount of water (Eliasson, 2005; Park *et al*., 2003; Hosseini and Jalilvand, 2007).

Initial road failure in our study area was indicated when the drivers complained about pot holes, surface

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rutting and roughness. Road surface deterioration increases driver fatigue, limits vehicle speed, reduces vehicle load capacity and accelerates vehicle maintenance requirements. In the transportation cost model used today in rural areas, the only road surface parameter is rut depth and only ruts deeper than 10 mm are considered to have any influence on traffic safety (Crossleya *et al*., 2001). The relation is then linear and transportation cost increases with increasing rut depth. Rural roads in Denji kola village have three types of surfacing layer which distinguishes it from other rural roads in region. Ruts on the surfaces of these roads are different in frequently, shape, width, depth and length according to geographical aspects, longitudinal gradient and surfacing layer.

From a road engineer's point of view, it may be helpful to analyze the deformed terrene roadbed structure based on various theoretical models and numerical calculations and apply these to a specified regional road condition. The objective of this research is to evaluate the factors affecting the deformation of the surface of rural road based on deep wheel rutting and shallow wheel rutting.

MATERIALS AND METHODS

Study area: The study was carried out in the Denji Kola Village in Ghaem Shahr City (36° 21' to 36° 38' N and 52° 43' to 53° 3' E), Mazandaran Province, Iran (Fig. 1). Average annual precipitation and temperature in this area are 724.9 mm and 16.7°C, respectively. Elevation at see level ranges from 64 to 98 m. During the rainy season months, the bare soil of the terrene rural roads in present study area become waterlogged and impassible, because there are little or no facilities for surface or subsurface drainage. During the dry season months, dust raised by the wheels of passing vehicles becomes a major environmental and health hazard.

The rural roads were under traffic by different types of machines in sandy clay loam soil. The mean of Shrinkage Limit (SL), Plastic Limit (PL) and Liquid Limit (LL) of soil in road bed were 6, 35 and 53%, respectively. Also, the average of soil bulk density and moisture content in rural roads were about 1.64 g cm^{-3} and 19%, respectively.

The ruts depth is correlated with wheel sinkage. Based on the rigid wheel theory, the rolling resistance coefficient (μ_R) depends on the wheel sinkage (z) and diameter (d) (Eq. 1). If, as assumed, the rut depth is equal to or linearly correlated with sinkage we can write the Eq. 2 for rut depth (Z_{RUT}) where, x is an empirical scale factor (Saarilahti and Anttila, 1999) (Fig. 2).

$$\mu_R = \sqrt{\frac{Z}{d}} \qquad (1)$$

$$Z_{RUT} = d\mu_R^2 x \qquad (2)$$

Data collection: The total length of rural road in Denji Kola village was investigated by field study. Deformation of the surface of rural road was divided in two classes. Class 1 was deep ruts and class 2 was shallow ruts (Fig. 3). The dimensions (width, depth and length) of all ruts were measured by metal meter and the longitudinal gradient at the place of each rut was taken by

Fig. 1: The geographical position of study area and road network (Mehrdadi *et al*., 2007)

inclinometer. The longitudinal gradient was divided in three classes 0-4, 4-8 and 8-12%. In addition, the slope aspect was classified in to Western, Eastern, Northern and Southern. The traffic condition and maintenance operations were same for all treatments.

Due to the high cost of paved roads a variety of unpaved road surface types are used. The surface of rural road in study area had three types of surfacing layers which were including bare soil roadbed, gravel-grassed roadbed and graveled roadbed. These roads require a much lower capital expenditure for construction but rely on ongoing regular maintenance to provide a functioning surface.

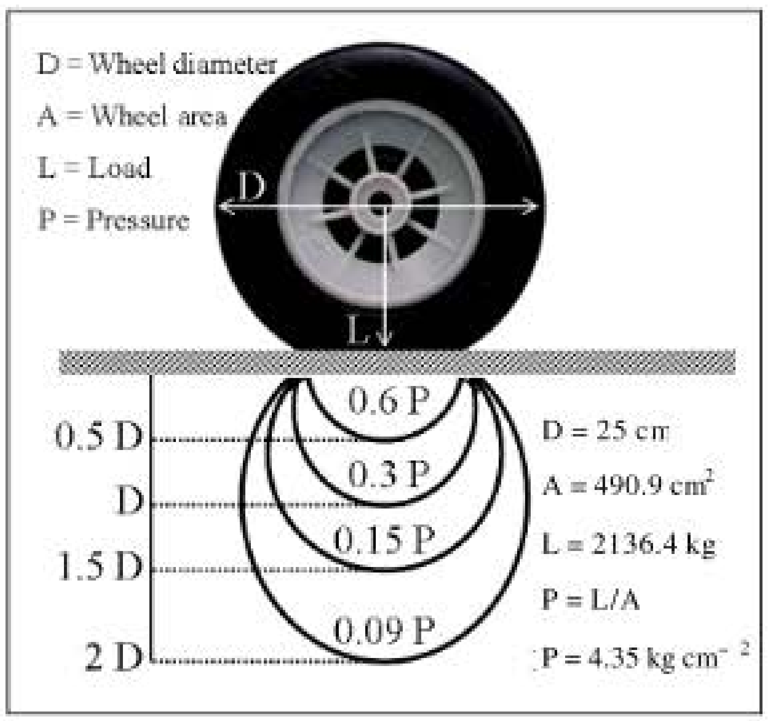

Fig. 2: Calculation of the tire pressure on road surface

Fig. 3: Deformation classifying on rural road surface (a) shallow wheel ruts and (b) deep wheel ruts

Statistical analysis: Analysis of variance was conducted using GLM procedures in SAS statistical programming software, respectively. Means were compared using Tukey's multiple group mean comparison test. Level of significance used in all results was $p<0.05$.

RESULTS AND DISCUSSION

Effect of the longitudinal gradient of rural road on wheel rutting: Rural roads across north of Iran are inadequate in coverage and quality. They are also usually poorly maintained and therefore poorly served by low-cost, high-volume transportation providers. An inadequate road infrastructure imposes significant burdens on rural road maintenance cost. Also, Farmers are faced with high farm-to-market access costs under unsuitable road condition (Raper *et al*., 1995; Obare *et al*., 2003). The minor rural road network in northern rural of Iran is an important part of the landscape structure. It sustains all agricultural activities by connecting farms, gardens and fields.

Results of this study showed that the ruts length ($p<0.0001$) and ruts area ($p<0.0001$) were significantly affected by longitudinal gradient of rural roads. There was not significant difference between the mean of ruts depth ($p = 0.153$) in different classes of longitudinal gradient (Table 1). This subject was also observed for ruts width ($p = 0.594$). Ruts length in longitudinal gradient class 8-12% was significantly more than other classes ($p<0.05$). The mean of ruts length in this class was 8.19 m (Fig. 4).

Table 1: Analysis of variance for the effect of longitudinal gradient of road on wheel rutting

Parameters	df	SS	MS	F-value
Rut depth	2	19.48	9.74	1.93^{ns}
Rut length	2	5075252.02	2537626.01	73.50***
Rut width	2	602.56	301.28	0.53^{ns}
Rut area	2	6790220718	3395110359	54.10***

***Significant at probability level of 0.1 %, ns: Not significant

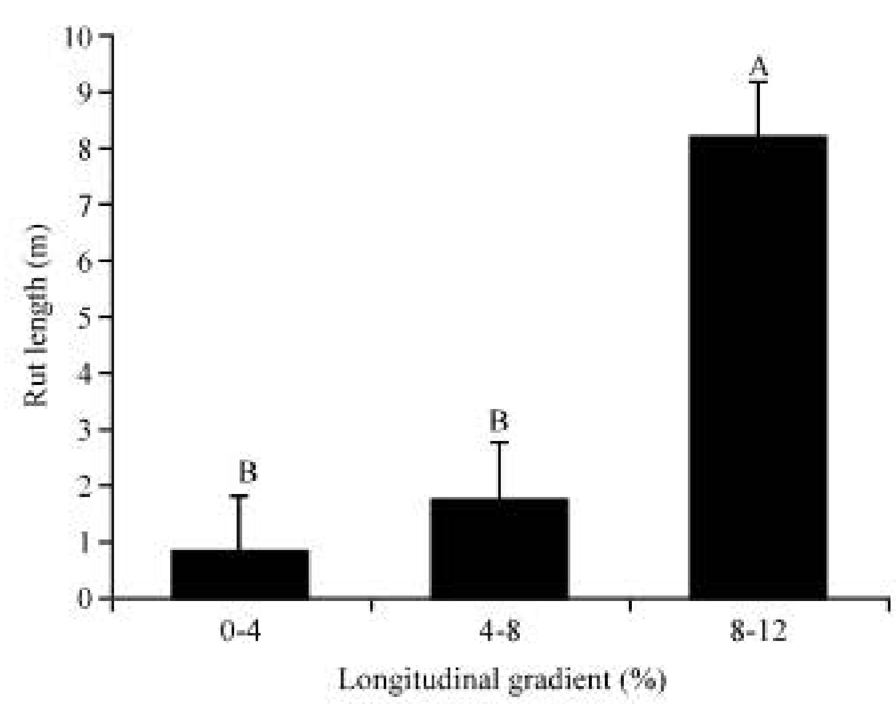

Fig. 4: Comparison of rut lengths in different classes of longitudinal gradient (different letter(s) show same groups according to Tukey test at $p<0.05$)

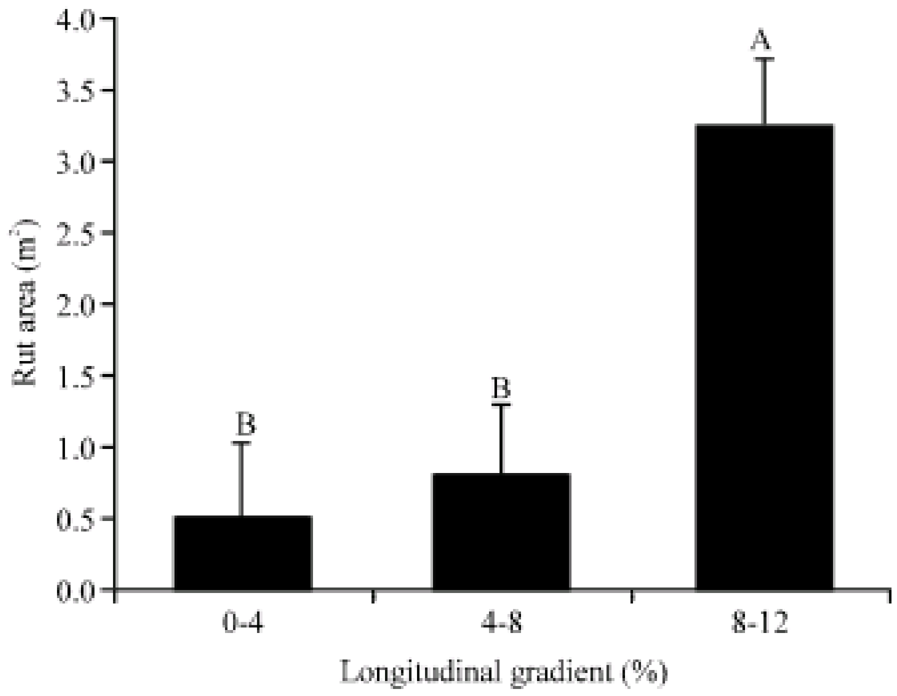

Fig. 5: Comparison of rut areas in different classes of longitudinal gradient (different letter(s) show same groups according to Tukey test at $p<0.05$)

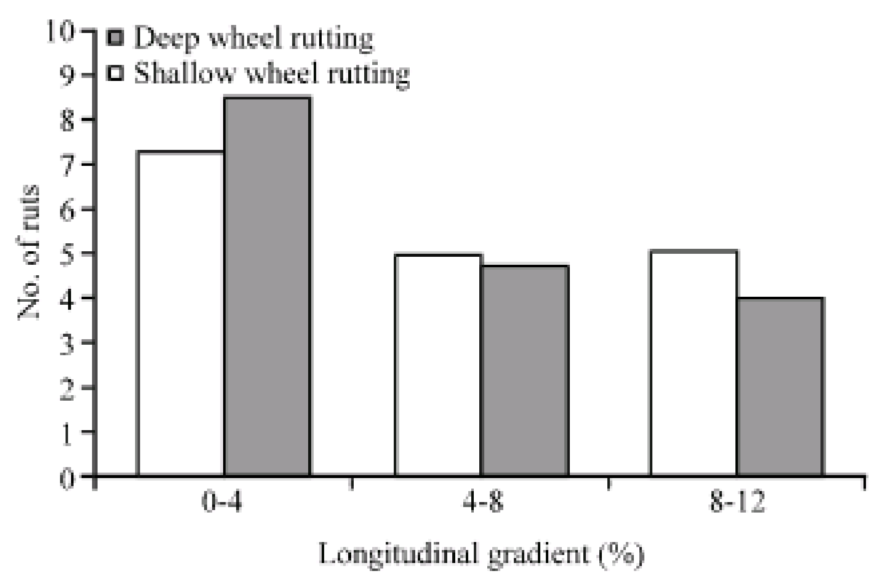

Fig. 6: Comparison of deep and shallow rut numbers in different classes of longitudinal gradient

The mean of ruts area in longitudinal gradient class 8-12% was significantly ($p<0.05$) more than other classes (Fig. 5). Also, the number of deep wheel ruts in class 0-4% was more than shallow wheel ruts, whereas the number of shallow wheel ruts was more than deep wheel ruts in other classes (Fig. 6).

Effect of the geographical aspect of rural road on wheel rutting: The analysis of the wheel load of a moving vehicle as well as the measurement of soil mechanical properties is of great importance for the basic investigation of wheel-soil interaction, tire characteristics as well as for the input and validation of vehicle dynamic simulations (Nguyen *et al*., 2008). In this study, the effect of geographical aspect did not significantly influence on ruts depth changes ($p = 0.305$), but the effects of the geographical aspect on ruts length ($p<0.0001$), ruts width ($p = 0.0019$) and ruts area ($p<0.0001$) was significant (Table 2).

The mean of ruts depth in eastern and southern aspects was significantly ($p<0.05$) more than other aspects (Fig. 7a). The ruts in northern aspect of rural road were significantly ($p<0.05$) longer than other aspects (Fig. 7b), but the ruts width in this aspect were significantly ($p<0.05$) less than southern, western and eastern aspects (Fig. 7c). Also, the area of ruts in northern aspect was significantly ($p<0.05$) higher than other aspects (Fig. 7d).

Effect of the surfacing layer of rural road on wheel rutting: Different types of surfacing layer in rural roads had significant effect on ruts width ($p<0.0001$). The ruts

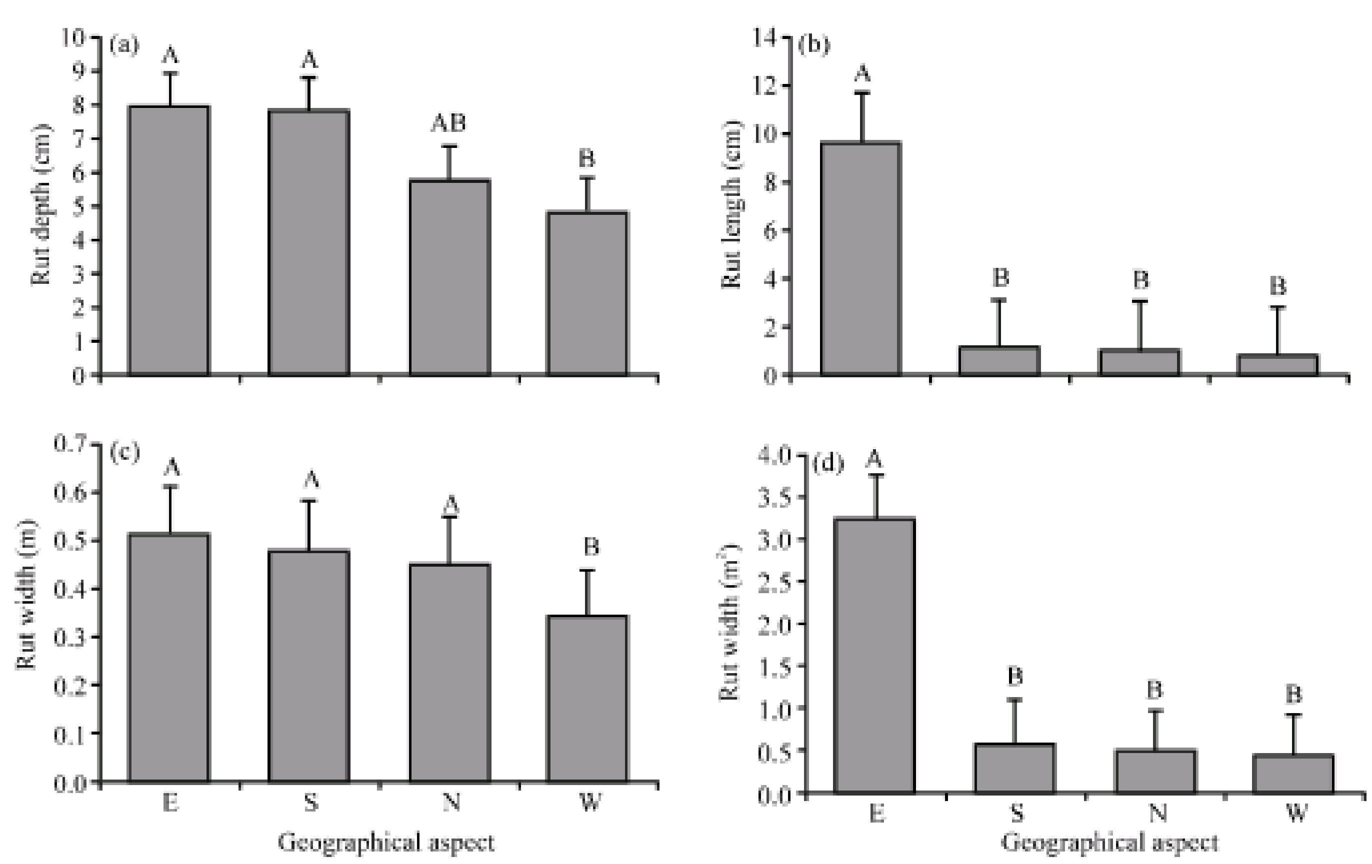

Fig. 7: (a) Comparison of ruts depth (b) ruts length (c) ruts width (d) and ruts areas in different geographical aspects of rural road (different letter(s) show same groups according to Tukey test at $p<0.05$)

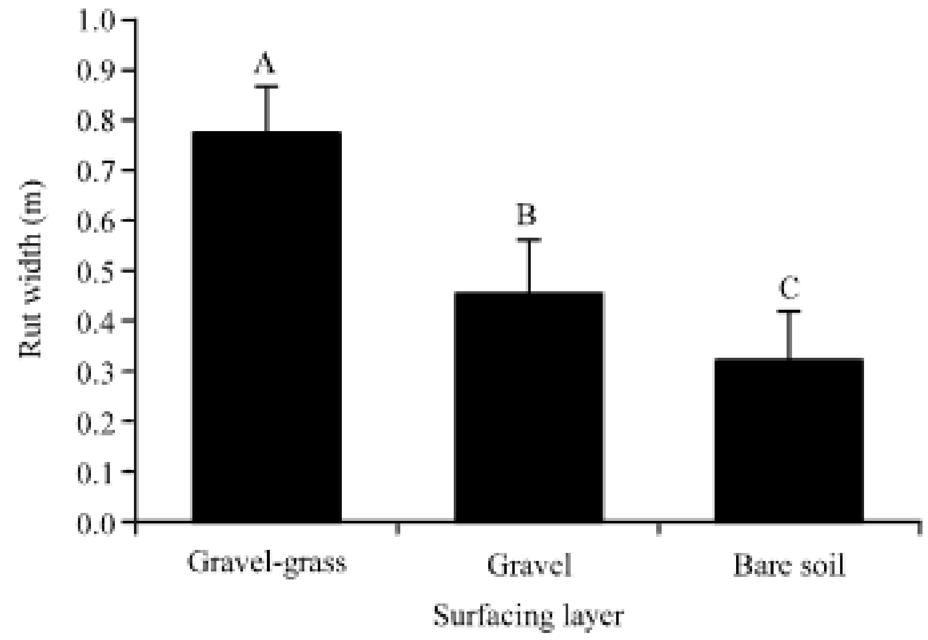

Fig. 8: Comparison of ruts width in different types of surfacing layers

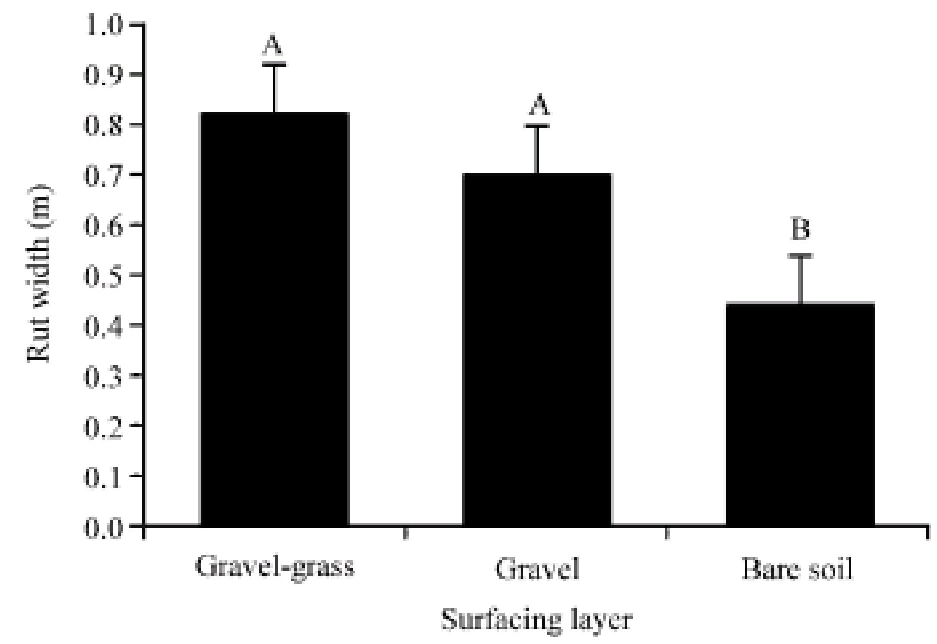

Fig. 9: Comparison of ruts depth in different types of surfacing layers

Table 2: Analysis of variance for the effect of geographical aspect on wheel rutting

Parameters	df	SS	MS	F-value
Rut depth	3	19.96	6.65	1.24^{ns}
Rut length	3	5982531.39	1994177.13	168.50***
Rut width	3	2250.30	750.10	5.85**
Rut area	3	6033592730	2011197577	102.54***

**, ***Significant at probability level 0.1 and 1.9%, respectively, ns: Not significant

Table 3: Analysis of variance for the effect of the type of surfacing layer on wheel rutting

Parameters	df	SS	MS	F-value
Rut depth	2	29.53	14.77	2.43^{ns}
Rut length	2	273797.01	136898.51	1.24^{ns}
Rut width	2	10071.41	5035.70	21.88***
Rut area	2	317259736.9	158629868.4	1.33^{ns}

*** Significant at probability level of 0.1 %; ns: Not significant

depth ($p = 0.096$), ruts length ($p = 0.297$) and ruts area ($p = 0.272$) were not significantly affected by different types of surfacing layer (Table 3). The mean of ruts width and ruts depth in gravel-grassed surface was significantly ($p<0.05$) more than other surfacing layers (Fig. 8). Bare soil had lowest rut width and depth (Fig. 9). These ruts were numerous on bare soil in surfacing layer.

In many European regions, structure and use of the minor rural road network have been changing rapidly during last decades. Changes in agricultural transport and a consequent demand for upgraded roads, changes in management of and impacts on road verges often lower landscape and nature qualities and increase conflicts between the different user groups of roads and verges (Pauwels and Gulinck, 2000). Local governments in Eastern European countries also face problems with budgets for local rural roads. Up to around 1990, the roads were under the responsibility of the collective farms (Jaarsma and Willems, 2002).

CONCLUSION

Rural roads connectivity is one of the key components for rural development, as it promotes access to economic and social services, generating increased agricultural income and productive employment, while building rural roads, the provisions based on the parameters that affect the sustainability are to be made, but at minimum cost. In most rural areas of the north of Iran, roads into and out of the citrus gardens are idle before harvest offering an ideal opportunity to plant grass on the roads as anti-erosion measure. The longitudinal gradient of rural roads must be reduced, because in steep sections of road the ruts length and consequently water erosion increases. Although, the ruts width and depth on gravel-grassed surface was more than other surfacing layer, the number of ruts in this surfacing layer was less than bare soil and graveled surfacing layer. Thus, thickness layer of gravel which has been covered by grass is the best mixture for surfacing layer of rural roads.

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