# AGGREGATE COMPOSITION AND WATER STABILITY OF STRUCTURAL AGGREGATES OF VERTISOLS SPREAD OUT IN ŠTIP, PROBIŠTIP AND OVČE POLE VALLEYS

Dalibor JOVANOV[1*], Tatjana MITKOVA[2] and Mite ILIEVSKI[1]

[1*] „Goce Delčev“ University, Faculty of Agriculture, Krste Misirkov b.b, 2000 Štip, Republic of Macedonia, e-mail: dalibor.jovanov@ugd.edu.mk, Tel: +38932550613, *correspondence

[2] „Ss Cyril and Methodius“ University, Faculty of Agricultural sciences and food, Blvd. Aleksandar Makedonski, b.b, 1000 Skopje, Republic of Macedonia

## ABSTRACT

Structure is the most striking, visual aspect of vertisol morphology. The type and degree of structure development in a vertisol provides a digest of its genesis, constituent properties and agriculture management potential. The present study includes the results of the investigations of aggregate composition and water stability of structural aggregates in all horizons (Ap, A, AC, C) of 7 vertisol profiles formed over tertiary clayish and pyroclastic sediments in the central part of Macedonia (Štip, Probištip and Ovče Pole valleys). The main objectives were to determine and compare aggregate composition and water stability of structural aggregates of vertisols which have been used as long-term arable fields (6 of the analyzed profiles) or as pasture (1 profile). The most represented fraction of aggregates in the process of dry sieving of the soil samples is the fraction of cloddy macro-aggregates (>10 mm), which is the most unfavourable from the agricultural point of view. Micro-aggregates fraction (<0.25 mm) is barely present, which means that in the dry state nearly all micro-aggregates and mechanical elements are associated in larger structural aggregates. The researched soils are characterized by different water stability of the structural aggregates. In the process of wet sieving, except surface horizon of the vertisol under natural vegetation, the cloddy macro-aggregates showed the greatest instability. With decrease of the dimension their stability increases so micro-aggregates have the highest water stability.

**Key words**: aggregate composition, clay, vertisol, water-stable aggregate

## INTRODUCTION

The World Reference Base for Soil Resources (IUSS Working Group WRB, 2007. World Reference Base for Soil Resources 2006, first update 2007) defined vertisols as churning, heavy clay soils with a high proportion of swelling clays. Alternate swelling and shrinking of expanding clays result in deep cracks in the dry season, and formation of „slickensides“ and wedge-shaped structural aggregates in the subsurface soil. This kind of structure with the described characteristics of the aggregates appears only in vertisols and because of that Driessen and Duddal (1989) named it as vertic.

Structure is an important physical feature of the soil that affects the nature and distribution of pores which hold water, air and allow roots to penetrate (Kerry and Oliver, 2007). According to Bronick and Lal (2005) soil structure exerts important influences on the edaphic conditions and environment. Seen from agricultural point of view, it is a fact that of all types of structure regarding the form and shape of the aggregates, the most favourable is the granular structure which enables mealy composition of the soil. According to Edwards (1991), the most favourable conditions for optimal growth of the plants are provided by mezzo-aggregates sized with 1-10 mm, while Veršinin (1958) as such considers the granular aggregates sized with 2-3 mm and close to them 1-2 and 3-5 mm. Beside the shape and form of the structural aggregates, their stability also has a very significant meaning. Mechanical stability of the aggregates and their stability in water contribute to maintenance of suitable relationship between the soil pores during the soil usage in agricultural production. The unstable structure reduces the infiltration and the water penetration, deteriorates the aeration and enables the appearance of thicker soil incrustation, by which irrigation erosion is intensified (Belič et al., 2004). In that context Amezketa (1999) accentuates that the stability of the structural aggregates is crucial characteristic that influences on soil sustainability and the cultivation of the plants.

Vertisols in Macedonia spread on about 61.900 ha or 2.41% of the whole soil surface (Filipovski, 1996). This type of soil is fairly well investigated, particularly genesis conditions and the genesis, evolution, classification, geography as well as the productive properties of the soil. So far only few studies on vertisol structure have been done (Filipovski, 1972; Filipovski et al., 1985; Petkovski, 1980; Spirovski, 1965). The objectives of this study were to determine and compare aggregate composition and water stability of structural aggregates of vertisols which have been used as arable fields for agricultural crops production (mainly wheat and barley) and vertisol under natural grass vegetation.

## MATERIALS AND METHODS

Field investigations of vertisols and soil sample collection have been performed according to Filipovski (red.), (1967). Seven basic soil profiles of the vertisols were rutted (Figure 1): profile N$^o$ 2 (Štip valley - 41°49'06.42" N, 22°11'59.71" E); profile N$^o$ 3 (Probištip valley - 41°56'24.86" N, 22° 07'19.19" E); profile N$^o$ 4 (Probištip valley - 41°57'27.28" N, 22°10'23.31" E ); profile N$^o$ 5 (Probištip valley - 41°54'20.74" N, 22° 09'47.95'' E); profile N$^o$ 7 (Probištip valley - 41°53'34.76" N, 22°11'05.64" E); profile N$^o$ 8 (Ovče Pole valley - 41°54'06.61" N, 21°52'48.55 E) and profile N$^o$ 9 (Ovče Pole valley - 41°53'54.74" N, 21°52'54.78" E). Six from previous mentioned profiles represent long-term arable vertisols (mainly wheat and barley) and 1 profile (N$^o$ 3) under pasture. Profiles N$^o$ 2, 8 and 9 are formed on tertiary clayish sediments while profiles N$^o$ 3, 4, 5 and 7 are formed on pyroclastic sediments (andesitic tuffs, ignimbrites and breccias').

Mechanical composition of these soils was determined by the International pipette method (Resulović (red.), 1971), and preparation of the soil samples for mechanic analysis was done by means of 0.4 N sodium pyrophosphate - $Na_4P_2O_7$ (Thurin et al., 1955). The fractioning of the mechanical elements was done according to the International Classification, while the classification of the soils in texture classes was done according to Schefer and Scachtcshabel (1956).

Aggregate size distribution was determined using a dry sieving method, according to Savvinov (Mitrikeski and Mitkova, 2001). Each sieved soil fraction was weighted and the results were used to calculate the percentage in the total weight of soil sample. Soil aggregate stability in water was determined using a wet sieving method, according to Savvinov (Mitrikeski and Mitkova, 2001).

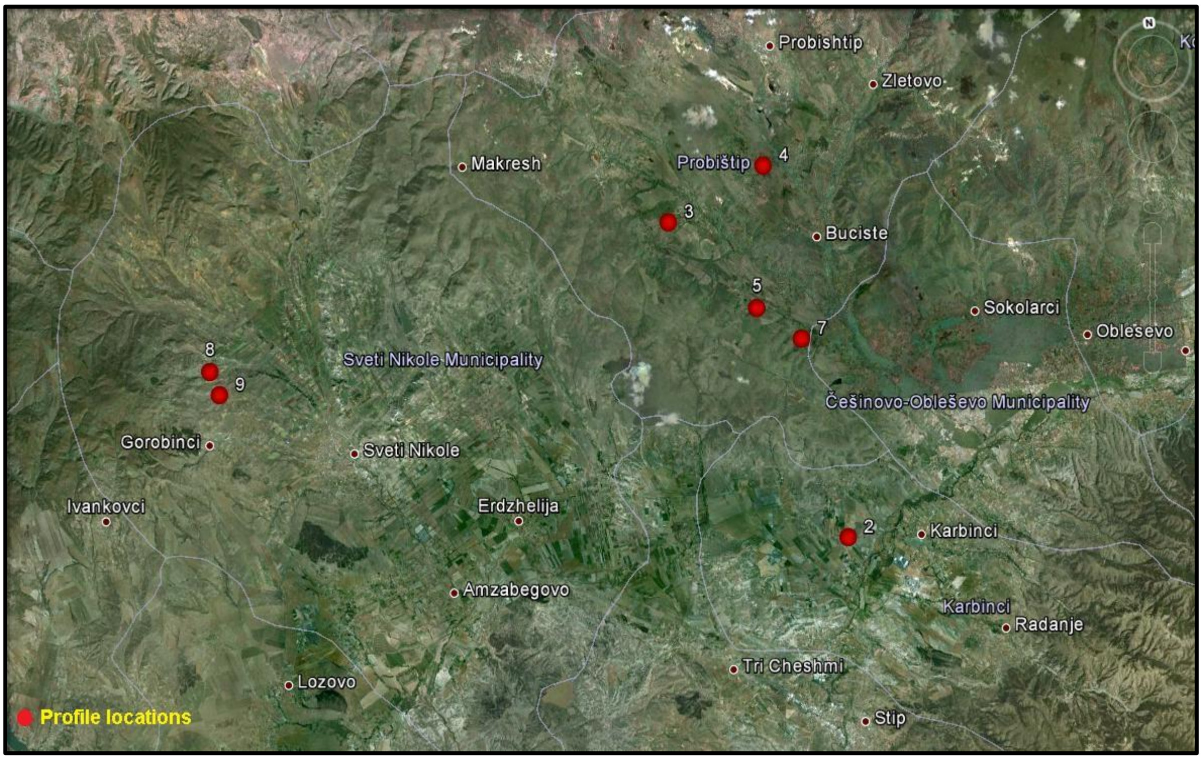


Figure 1. Locations of investigated vertisol profiles

## RESULTS AND DISCUSSION

### Mechanical composition (Texture)

From the given data of the mechanical composition of the studied profiles (Table 1), the most important are the data about the clay content (colloid particles smaller than 0,002 mm), because this fraction has a great impact on the aggregate composition of the soil. This fraction participates with 24.60% to 52.50% in the soils, most frequently higher than 35%.

The results of the textural analysis show that 24 of the total 29 analyzed samples belong to loamy clays, 3 samples belong to heavy clays and only 1 sample to sandy clay and sandy-loam clay.

Table 1. Mechanical composition of vertisols (international method B)

| Profile Nº | Horizons and depth in cm | CF | Fine soil separates in % | | | | Textural classes |
|---|---|---|---|---|---|---|---|
| | | | CS | FS | S | C | |
| 2 | Ap (0-23) | 1.80 | 18.96 | 25.54 | 16.90 | 38.60 | LC |
| | A (23-75) | 1.68 | 18.65 | 26.65 | 11.00 | 43.70 | LC |
| | AC (75-95) | 1.01 | 23.23 | 24.17 | 12.20 | 40.40 | LC |
| | C (95-115) | 0.41 | 24.34 | 24.36 | 17.20 | 34.10 | LC |
| 3 | A (0-40) | 1.07 | 8.36 | 28.84 | 26.00 | 36.80 | LC |
| | AC (40-80) | 0.11 | 4.36 | 29.94 | 28.40 | 37.30 | LC |
| | C (80-110) | 0.02 | 5.15 | 24.95 | 25.80 | 44.10 | LC |
| 4 | Ap (0-21) | 0.83 | 23.64 | 35.06 | 10.90 | 30.40 | SC |
| | A (21-39) | 0.68 | 13.96 | 26.94 | 17.60 | 41.50 | LC |
| | Aca (39-73) | 0.84 | 18.57 | 27.63 | 14.20 | 39.60 | LC |
| | AC (73-97) | 0.57 | 22.65 | 26.85 | 14.90 | 35.60 | LC |
| | C (97-115) | 1.21 | 47.10 | 16.80 | 11.50 | 24.60 | SLC |
| 5 | Ap (0-18) | 2.19 | 3.74 | 27.36 | 28.80 | 40.10 | LC |
| | A (18-73) | 0.26 | 6.57 | 24.03 | 20.80 | 48.60 | HC |
| | AC (73-107) | 0.21 | 4.83 | 15.87 | 27.70 | 51.60 | HC |
| | C (107-130) | 0.04 | 3.57 | 10.23 | 33.70 | 52.50 | HC |
| 7 | Ap (0-26) | 2.60 | 22.08 | 23.82 | 15.40 | 38.70 | LC |
| | A (26-54) | 2.94 | 23.36 | 23.04 | 18.00 | 35.60 | LC |
| | Aca (54-105) | 1.20 | 16.29 | 24.61 | 15.60 | 43.50 | LC |
| | AC (105-150) | 1.06 | 15.21 | 18.89 | 23.50 | 42.40 | LC |
| | C (150-165) | 0.76 | 19.35 | 27.35 | 15.60 | 37.70 | LC |
| 8 | Ap (0-32) | 0.51 | 5.95 | 30.55 | 28.90 | 34.60 | LC |
| | A (32-70) | 0.50 | 5.66 | 27.44 | 24.50 | 42.40 | LC |
| | AC (70-113) | 0.25 | 4.62 | 25.48 | 25.30 | 44.60 | LC |
| | C (113-125) | 0.71 | 5.84 | 24.76 | 30.10 | 39.30 | LC |
| 9 | Ap (0-25) | 0.50 | 6.23 | 27.87 | 30.30 | 35.60 | LC |
| | A (25-68) | 0.47 | 4.93 | 25.17 | 28.20 | 41.70 | LC |
| | AC (68-113) | 0.07 | 2.50 | 24.00 | 30.70 | 42.80 | LC |
| | C (113-125) | 0.19 | 3.08 | 18.58 | 35.24 | 43.10 | LC |

CF: coarse fragments (>2mm); CS: coarse sand (0,2 - 2mm); FS: fine sand (0,02 - 0,2 mm); S: sand (0,002 - 0,02 mm); C: clay (< 0,002 mm); LC: loamy clay; SC: sandy clay; SLC: sandy loamy clay; HC: heavy clay.

**Aggregate composition (Dry sieving)**

Before explaining results of the aggregate composition we should take into consideration the fact that the determined position of the structure, the correlation and the content of the separate fractions of the structural aggregates is shortlived appearance. The results of the aggregate composition of the examined vertisols (dry sieving) are given in Table 2.

Table 2. Aggregate composition of vertisols – dry sieving

| Pr. N° | Horizons and depth in cm | Aggregate content in % | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | > 10 mm | 10-5 mm | 5-3 mm | 3-2 mm | 2-1 mm | 1-0.5 mm | 0.5-0.25 mm | <0.25 mm |
| 2 | Ap (0-23) | 42.40 | 11.57 | 27.99 | 14.68 | 1.38 | 0.82 | 0.51 | 0.65 |
| | A (23-75) | 47.08 | 12.62 | 23.85 | 10.51 | 2.31 | 1.73 | 0.69 | 1.21 |
| | AC (75-95) | 46.71 | 12.05 | 23.41 | 10.08 | 3.51 | 2.55 | 0.53 | 1.16 |
| | C (95-115) | 59.75 | 12.48 | 11.50 | 5.70 | 5.04 | 2.60 | 0.79 | 2.14 |
| 3 | A (0-40) | 42.50 | 10.67 | 12.75 | 10.33 | 11.22 | 6.99 | 3.54 | 2.00 |
| | AC (40-80) | 48.42 | 9.37 | 11.07 | 10.38 | 12.65 | 5.38 | 1.13 | 1.60 |
| | C (80-110) | 43.47 | 12.25 | 17.37 | 9.75 | 9.75 | 5.36 | 0.65 | 1.40 |
| 4 | Ap (0-21) | 65.23 | 8.66 | 11.37 | 6.61 | 3.26 | 2.66 | 0.88 | 1.33 |
| | A (21-39) | 69.33 | 8.55 | 9.85 | 5.13 | 4.37 | 1.72 | 0.38 | 0.67 |
| | Aca (39-73) | 65.83 | 8.50 | 12.35 | 5.52 | 4.32 | 2.12 | 0.38 | 0.98 |
| | AC (73-97) | 79.69 | 6.69 | 6.51 | 2.49 | 2.21 | 1.29 | 0.33 | 0.79 |
| | C (97-115) | 61.16 | 11.71 | 15.37 | 7.17 | 2.49 | 1.30 | 0.26 | 0.54 |
| 5 | Ap (0-18) | 58.63 | 13.71 | 15.88 | 6.03 | 2.73 | 1.42 | 0.42 | 1.18 |
| | A (18-73) | 57.99 | 13.79 | 20.10 | 5.21 | 1.32 | 0.90 | 0.25 | 0.44 |
| | AC (73-107) | 60.96 | 11.22 | 18.34 | 7.18 | 1.08 | 0.70 | 0.13 | 0.39 |
| | C (107-130) | 70.18 | 6.79 | 9.16 | 4.58 | 5.15 | 1.09 | 1.99 | 1.06 |
| 7 | Ap (0-26) | 43.83 | 12.77 | 26.03 | 11.68 | 2.74 | 1.47 | 0.46 | 1.02 |
| | A (26-54) | 43.65 | 13.89 | 26.09 | 10.88 | 2.49 | 1.48 | 0.54 | 0.98 |
| | Aca (54-105) | 49.34 | 12.59 | 25.68 | 7.95 | 2.32 | 1.24 | 0.29 | 0.59 |
| | AC (105-150) | 58.95 | 13.85 | 18.49 | 6.17 | 1.17 | 0.72 | 0.19 | 0.46 |
| | C (150-165) | 56.51 | 12.94 | 18.87 | 7.33 | 1.73 | 1.35 | 0.36 | 0.91 |
| 8 | Ap (0-32) | 70.25 | 7.58 | 9.34 | 5.42 | 4.09 | 1.84 | 0.57 | 0.91 |
| | A (32-70) | 59.90 | 8.29 | 11.30 | 7.89 | 7.56 | 3.35 | 0.58 | 1.13 |
| | AC (70-113) | 57.45 | 11.03 | 11.21 | 6.20 | 7.70 | 4.22 | 1.20 | 0.99 |
| | C (113-125) | 58.79 | 9.79 | 12.48 | 5.50 | 8.15 | 3.07 | 1.55 | 0.67 |
| 9 | Ap (0-25) | 51.87 | 13.16 | 21.58 | 8.49 | 1.93 | 1.45 | 0.38 | 1.14 |
| | A (25-68) | 51.53 | 12.36 | 24.29 | 8.31 | 1.85 | 0.97 | 0.21 | 0.48 |
| | AC (68-113) | 46.93 | 12.43 | 26.72 | 8.94 | 2.70 | 1.30 | 0.29 | 0.69 |
| | C (113-125) | 49.16 | 12.98 | 23.45 | 9.92 | 2.53 | 1.19 | 0.24 | 0.53 |

Heavy mechanical composition with domination of the clay fraction in the soil separates has a reflection on the soil structure which is main reason for domination of the cloddy macro-aggregates bigger than 10 mm through the whole deepness of the examined soils. The content of these aggregates varies from 42.40% (profile N° 2) to 79.69% (profile N° 4), or average about 56.56%. Considering the humus-accumulative horizon A the average presence of these aggregates is 55.96% and it varies from 42.40% (profile N° 2) to 70.25% (profile N° 8). Macro-aggregates bigger than 10 mm together with those bigger than 5 mm have average presence of 67%. Studying the vertisols of Maleš and Pijanec, Filipovski et al. (1985) found similar average values for presence of these aggregates. Second place is taken by the fraction of the granular aggregates (1-5 mm) with an average presence of 29.25%. They are most advantageous from the agronomic point of view. Smaller aggregates are less present, therefore the micro aggregates (< 0.25 mm) in dry condition are barely present (average only 0.97%). We can conclude that practically all micro-aggregates and mechanical elements are connected in the bigger macro-aggregates (Figures 2 and 3).

Figure 2. Cloddy aggregate with „slickensides“ (profile N$^{o}$ 9)

Figure 3. Polyedric structure of vertisol (profile N$^{o}$ 2)

From the results of dry sieving of the soil samples we can see that during the dry periods, clay soil agglutinates mainly in compact and on mechanical attacks very resistant „wedge-shaped“ structure, with big prismatic and polyedric structural aggregates separated by fractures and mechanically strongly resistant to decomposition. This kind of structure creates large problems during the cultivation of the vertisols. When the soil is dry, the plough hardly enters in the soil and during the tillage big blocks of soil are formed which after can be hardly crumbled.

**Water stability of structural aggregates (Wet sieving)**

According to Pavićević (1969), the structural aggregates in the vertisols shows different stability which is also confirmed in our research (Table 3).

Table 3. Aggregate composition of vertisols – wet sieving

| Pr. N° | Horizons and depth in cm | Aggregate content in % | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | >5 mm | 5-3 mm | 3-2 mm | 2-1 mm | 1-0.5 mm | 0.5-0.25 mm | <0.25 mm | >0.25 mm |
| 2 | Ap (0-23) | 4.66 | 12.27 | 30.87 | 26.29 | 9.73 | 3.70 | 12.48 | 87.52 |
| | A (23-75) | 1.15 | 0.98 | 39.15 | 35.17 | 2.65 | 2.21 | 18.69 | 81.31 |
| | AC (75-95) | 0.59 | 8.70 | 32.98 | 27.70 | 10.26 | 3.91 | 15.86 | 84.14 |
| | C (95-115) | 24.17 | 8.12 | 32.55 | 31.44 | 2.57 | 1.09 | 10.06 | 89.94 |
| 3 | A (0-40) | 13.47 | 27.82 | 22.65 | 26.17 | 2.15 | 4.22 | 3.52 | 96.48 |
| | AC (40-80) | 2.17 | 0.90 | 9.15 | 7.89 | 29.15 | 37.22 | 13.52 | 86.48 |
| | C (80-110) | 6.15 | 3.75 | 11.21 | 6.14 | 19.95 | 35.15 | 17.65 | 82.35 |
| 4 | Ap (0-21) | 3.45 | 2.27 | 6.17 | 5.03 | 40.17 | 24.66 | 18.25 | 81.75 |
| | A (21-39) | 9.17 | 3.96 | 4.35 | 11.16 | 34.28 | 19.87 | 17.21 | 82.79 |
| | Aca (39-73) | 4.62 | 1.05 | 8.12 | 17.06 | 33.15 | 15.29 | 20.71 | 79.29 |
| | AC (73-97) | 2.55 | 3.15 | 11.16 | 10.67 | 30.65 | 14.99 | 26.83 | 73.17 |
| | C (97-115) | 2.97 | 5.88 | 4.78 | 15.09 | 29.99 | 13.70 | 27.59 | 72.41 |
| 5 | Ap (0-18) | 0.87 | 6.17 | 4.55 | 17.15 | 18.02 | 29.22 | 24.02 | 75.98 |
| | A (18-73) | 1.00 | 0.12 | 4.04 | 19.65 | 19.09 | 33.07 | 23.03 | 76.97 |
| | AC (73-107) | 2.50 | 4.90 | 2.85 | 17.15 | 18.16 | 33.46 | 20.98 | 79.02 |
| | C (107-130) | 1.45 | 2.10 | 1.17 | 11.66 | 28.15 | 30.77 | 24.70 | 75.30 |
| 7 | Ap (0-26) | 25.16 | 13.29 | 19.65 | 18.35 | 6.33 | 4.93 | 12.29 | 87.71 |
| | A (26-54) | 14.29 | 0.88 | 27.00 | 24.80 | 10.03 | 9.97 | 13.03 | 86.97 |
| | Aca (54-105) | 6.38 | 4.15 | 34.66 | 33.89 | 3.78 | 2.07 | 15.07 | 84.93 |
| | AC (105-150) | 2.70 | 9.66 | 28.17 | 25.66 | 9.44 | 5.09 | 19.28 | 80.72 |
| | C (150-165) | 16.99 | 14.22 | 13.26 | 17.98 | 12.60 | 7.62 | 17.33 | 82.67 |
| 8 | Ap (0-32) | 0.25 | 4.22 | 6.15 | 10.60 | 35.16 | 22.94 | 20.68 | 79.32 |
| | A (32-70) | 1.13 | 7.23 | 0.65 | 9.55 | 37.92 | 24.41 | 19.11 | 80.89 |
| | AC (70-113) | 0.68 | 2.00 | 4.48 | 15.65 | 34.16 | 16.76 | 26.27 | 73.73 |
| | C (113-125) | 0.84 | 8.30 | 8.03 | 8.16 | 29.66 | 26.93 | 18.08 | 81.92 |
| 9 | Ap (0-25) | 2.15 | 0.88 | 5.15 | 15.01 | 20.78 | 25.70 | 30.33 | 69.67 |
| | A (25-68) | 2.24 | 2.01 | 6.68 | 16.14 | 20.39 | 28.63 | 23.91 | 76.09 |
| | AC (68-113) | 1.45 | 4.25 | 11.24 | 19.10 | 16.33 | 22.48 | 25.15 | 74.85 |
| | C (113-125) | 0.22 | 0.44 | 3.88 | 13.17 | 17.25 | 25.60 | 39.44 | 60.56 |

During the wet sieving the most unstable were the macro-aggregates (>10 mm) which during the dry sieving were mostly present. With decreasing of the dimension their stability increases, so micro-aggregates have the highest stability. In profiles N° 2 and 7, aggregates larger than 3 mm are decomposed the most in aggregates from 1 to 3 mm, while in profiles N° 4, 5, 8, and 9 in aggregates from 0,25 to 1 mm. A significant part of the aggregates decomposed into micro-aggregates and mechanical elements (in profiles N° 5, 8 and 9 in Ap horizon over 20%, and in profiles N° 2, 4 and 7 from 12 to 18%). An exception of this tendency is profile N° 3 which is under natural vegetation (only 3.52% in the surface horizon and from 13.52 to 17.65 in the horizons below). Also, in the surface horizon aggregates larger than 3 mm are more present (41.29%) than in the AC horizon without any influence of the root system on the herbage (3.07%). That means that in this vertisol the stability of the aggregates in the layer under the influence of the root system is much higher. The result of the present study for this characteristic is in agreement with the results of Spirovski (1965) for vertisols formed over basic rocks. These data indicate that with phytomelioration (cultivation of perennial plants) the structure can be improved not only because of the higher water stability of the aggregates but also of the tight thin veins from the voluminous mass of the root system which penetrate trough the soil in different directions and crumble the larger aggregates (Table 3, 53.17% in horizon A and 57.79% in horizon AC at profile N$^o$ 3).

## CONCLUSION

Based on the results of aggregate composition and water stability of the structural aggregates of vertisols from area of central Macedonia, the following may be concluded:

- The investigated vertisols show very unfavourable textural characteristics. The domination of the clay fraction in the soil separates strongly reflects the vertisols structure.
- During the dry sieving of the soil samples the fractions of aggregates larger than 10 mm dominate (in average 56.56%). Aggregates larger than 10 mm, together with those larger than 5 mm, have an average presence of 66.96%. Aggregates which are the most suitable from the agronomic point of view (1-5 mm) take the second place (29.25%). Smaller aggregates are less present, therefore micro-aggregates (<0.25 mm) in dry condition are barely present (0.97%). That means that in dry condition all micro-aggregates and mechanical elements are practically connected in bigger aggregates.
- Wet sieving shows the stability of the macro-aggregates. In profiles N$^o$ 2 and 7 larger aggregates are decomposed the most in aggregates from 1 to 3 mm, while in profiles N$^o$ 4, 5, 8 and 9 in aggregates from 0.25 to 1 mm. A significant part of the aggregates decomposes in micro-aggregates and mechanical elements (in profiles N$^o$ 5, 8 and 9 in Ap horizon over 20%, and in profiles N$^o$ 2, 4 and 7, from 12 to 18%). An exception is the profile N$^o$ 3 which is under natural vegetation (only 3.52% in A, and under it from 13.52 to 17.65%). In the humus-accumulative horizon of this profile the aggregates larger than 3 mm remain stable in much higher quantity (41.29%) than in AC horizon without an impact of the root system (3.07%). That means that in this vertisol the stability of the macro-aggregates in the horizon which is under the impact of the root system is much higher.

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