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Soil Moisture Classification in Northwestern Washington

Abstract

Since little documentation is available for classifying soil moisture in northwestern Washington, the objective of this study was to classify the soil moisture regime of the Whatcom soil, the soil of largest extent in the area. The moisture content of this soil was determined by comparing the weight of water in each field sample collected weekly or biweekly with its respective oven-dried weight. The research was conducted from 1981 to 1985 during the critical summer months when the soils dry from evapotranspiration and when precipitation reaches its annual minimum. In Whatcom soils, as well as for other upland soils in western Washington, the deciding factor for classifying the soil moisture regime according to *Soil Taxonomy* is the amount of time the soil moisture control section is dry in all parts to a tension more than 1.5 M Pa. A comparison of the soil moisture data for 1981 to 1985 with the corresponding five years of precipitation and extrapolating the relationship to the total 35 years of climatic record indicates that Whatcom soils do not dry to tensions >1.5 M Pa for sufficient time to classify the soil moisture regime as xeric, the current classification. The appropriate classification appears to be udic. These findings may have an impact on studies on plant moisture uptake and summer irrigation in western Washington.

Introduction

Soil moisture has been classified from a climatological (Thornthwaite 1948) as well as a soils perspective (Soil Survey Staff 1975). In western Washington, soil moisture has eluded classification due to the variable summer precipitation. Although the climate appears to typify a Mediterranean type, in which summer precipitation is dramatically lower than the winter maximum, it actually qualifies as a Marine west-coast climate based on the ratio of July precipitation to evapotranspiration (Strahler and Strahler 1983).

Soil moisture classification schemes are usually based on some interrelationship between soils and plants, although Thomas *et al.* (1973) found that soils in western Oregon could not be grouped clearly into xeric and udic moisture regimes using such a system. *Soil Taxonomy*, in particular, uses the seasonal distribution of precipitation, the amount of time and depth the soil is saturated, and the amount of time the soil moisture control section is dry to a tension less than 1.5 M Pa (Soil Survey Staff 1975). The intent in defining the soil moisture control section is to facilitate estimating soil moisture regimes from climatic data.

Many of the soils in the mesic temperature regime above the flood plain in western Washington are currently classified in the xeric moisture regime (Soil Conservation Service 1984). These soils become moist from a combination of capillary movement from the high water table, lateral flow, and rainfall. There is little, if any, documentation showing the quantitative relationship between climate and changes in soil moisture in northwestern Washington and, thus, to establish if there is sufficient soil water to keep the moisture control section below a tension of 1.5 M Pa and prevent the consecutive days of dryness for a xeric moisture regime. This study was undertaken to produce some base data for soils in the northern part of this region, to estimate the soil moisture regime from climatic data, and to test the taxonomic placement of the soils in the xeric moisture regime.

Methods

The soils examined are the established Whatcom series, which are fine-loamy, mixed, mesic Aqualfic Haplorthods, based on the presence of silt pellets and cracked coatings in the Bs horizon and argillans in the 2Bt horizon (Table 1). They formed in glacialmarine drift with an admixture of loess and volcanic ash (Goldin 1988). The closest climatic record to the study site is taken at the Bellingham station, which is located 13 km southeast at an elevation of 30 m (Table 2). No measurements were taken on-site, but other nearby stations, such as the Clearbrook station 28 km northeast, show similar summer rainfall patterns.

The moisture contents at 1.5 M Pa and 33 k Pa were measured by the USDA National Soil Survey Laboratory using standard procedures (Soil Conservation Service 1972) (sample number

TABLE 1. Typical pedon of the Whatcom series, on a 2 percent south-facing slope in pasture at 50 m elevation.

Ap—0 to 23 cm; dark brown (10YR 3/3) silt loam, brown (10YR 5/3) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic, weakly smeary; many fine and common fine roots; many very fine irregular pores; 5 percent pebbles and 2 percent concretions; NaF pH 10.5; medium acid (pH 6.0); abrupt smooth boundary.

Bsl—23 to 33 cm; dark brown (7.5YR 4/4) silt loam, light brown (7.5YR 6/4) dry; weak fine subangular blocky structure; soft, very friable, nonsticky, nonplastic, weakly smeary; many very fine roots; many very fine irregular pores; 5 percent pebbles and 1 percent concretions; NaF pH 11.5; medium acid (pH 6.0); clear smooth boundary.

Bs2—33 to 41 cm; dark brown (7.5YR 3/4) silt loam, light brown (7.5YR 6/4) dry; weak fine subangular blocky structure; soft, very friable, nonsticky, nonplastic, weakly smeary; many very fine roots; many very fine irregular pores; 5 percent pebbles and 1 percent concretions; NaF pH 12.0; medium acid (pH 6.0); abrupt smooth boundary.

2Btl—41 to 51 cm; light olive brown (2.5Y 5/4) loam, pale yellow (2.5Y 7/4) dry; many medium prominent mottles of dark yellowish brown (10YR 4/4), yellowish brown (10YR 5/4) dry; medium thick platy struture; slightly hard, friable, slightly sticky, slightly plastic; common very fine roots; many very fine irregular pores; few, thin patchy clay films on faces of peds; 5 percent pebbles; NaF pH 9.8; medium acid (pH 6.0); clear smooth boundary.

2Bt2—51 to 66 cm: light olive brown (2.5Y 5/4) loam, light gray (2.5Y 7/2) dry; many coarse prominent mottles of yellowish brown (10YR 5/6), reddish yellow (7.5YR 6/6) dry; moderate thick platy structure; slightly hard, friable, nonsticky, nonplastic; few very fine roots; many very fine irregular pores; few, thin patchy clay films on faces of peds; 10 percent pebbles; NaF pH 10.0; medium acid (pH 6.0); abrupt smooth boundary.

2C1—66 to 89 cm; light olive gray (5Y 6/2) loam, white (5Y 8/2) dry; many medium prominent mottles of light olive brown (2.5Y 5/6) moist and dry; moderate thick platy structure; very hard, firm, slightly sticky, slightly plastic; common very fine irregular pores; 5 percent pebbles; NaF pH 9.4; neutral (pH 6.6); clear smooth boundary.

2C2—89 to 150 cm; dark gray (5Y 4/1) loam, light gray (5Y 7/1) dry; moderate coarse blocky structure; extremely hard, very firm, slightly sticky, slightly plastic; very few very fine irregular pores; 5 percent pebbles; NaF pH 9.6; mildly alkaline (pH 7.6); slightly effervescent.

TABLE 2. Total precipitation record for the months of June through September for Bellingham, Washington, 1951-1985. Values in mm.

Year	June	July	August	September	4 Month Sum
1951	5.6	2.0	9.9	37.3	54.8
1952	50.5	14.5	8.1	22.3	95.4
1953	51.2	20.5	22.6	52.7	147.0
1954	50.2	37.8	58.8	30.4	177.2
1955	49.2	44.9	6.8	29.1	130.0
1956	115.4	3.6	34.5	84.2	237.7
1957	41.8	50.0	17.5	23.3	132.6
1958	19.5	0.0	7.4	48.4	75.3
1959	34.7	12.9	33.7	108.0	189.3
1960	31.7	0.0	68.5	53.8	154.0
1961	23.1	34.0	30.4	41.1	128.6
1962	37.5	9.6	119.2	60.1	226.4
1963	32.0	52.7	10.9	26.1	121.7
1964	48.9	60.9	44.9	102.2	256.9
1965	13.2	5.8	92.6	34.5	146.1
1966	26.6	66.7	23.1	53.0	169.4
1967	30.2	19.5	8.4	52.5	110.6
1968	71.5	28.1	80.1	65.9	245.6
1969	38.0	13.4	15.2	141.5	208.1
1970	34.2	41.6	4.3	63.7	141.6
1971	85.5	44.6	7.4	105.8	243.3
1972	59.1	63.9	36.3	53.0	212.3
1973	36.3	9.6	17.8	35.5	99.2
1974	38.3	50.0	3.0	12.7	104.0
1975	30.2	45.6	92.6	12.2	180.6
1976	53.0	20.5	67.5	27.6	168.6
1977	18.3	38.3	52.5	46.4	155.5
1978	53.3	15.5	68.0	110.3	247.1
1979	58.8	29.7	40.6	48.4	177.5
1980	84.4	40.1	23.8	72.5	220.8
1981	104.7	61.9	14.7	56.0	237.3
1982	31.4	83.9	26.6	32.5	174.4
1983	44.9	66.4	28.7	104.5	244.5
1984	64.1	3.0	50.2	82.4	199.7
1985	54.3	2.5	2.8	53.5	113.1
mean	46.3	31.3	35.1	56.7	169.3
s	24.0	23.3	29.8	31.2	55.1
mean (81-85)	59.9	43.5	24.6	65.8	193.8
s (81-85)	27.8	38.1	17.7	28.0	53.4

S81WA-073-008). The change in soil moisture was examined for five consecutive years during May through October. Several moisture analyses made between October and May showed the soils to remain at or near field capacity. The gravimetric moisture content was determined at approximately one to three week intervals during the sampling period (Figures 1 and 2). Gravimetric moisture analysis is the standard for soil moisture (Schmugge *et al.* 1980, McKim *et al.* 1980) and

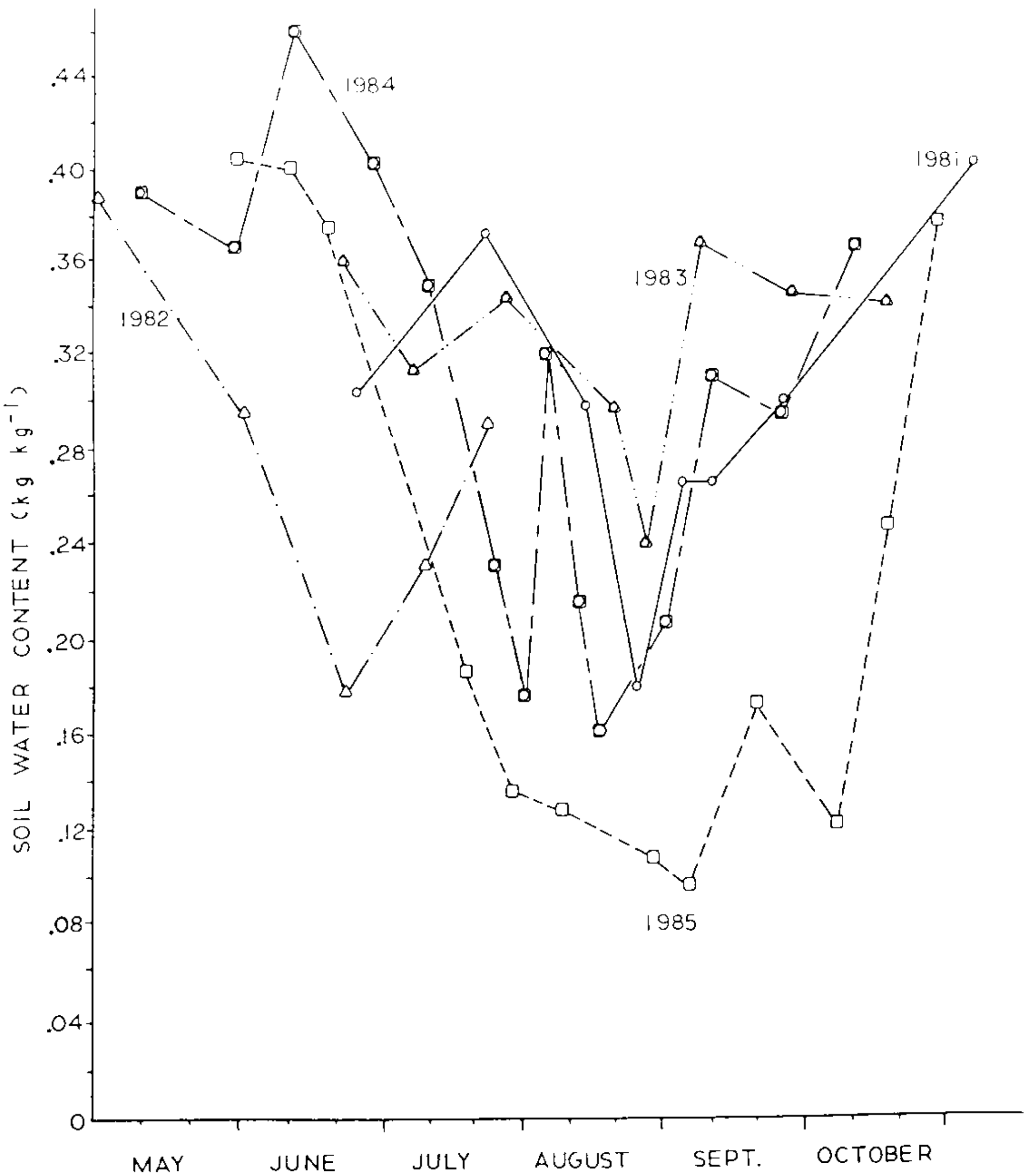

Figure 1. Changes in soil moisture content in the Whatcom series at 0.1 to 0.15 m during May through October 1981-1985.

was used for that reason. Sample acquisition is fast and inexpensive and covers the pressure potential range from 0 to more than 1.5 M Pa.

Samples were taken from 10 small pits adjacent to the type location of the series. This site is in pasture and is not irrigated. Moisture analyses, at several locations in an adjacent woodland site, were made starting in 1982, since it was assumed the soil under forest would be dryer due to greater transpiration. However, the moisture levels were almost identical to those at the type locations in pasture so only occasional

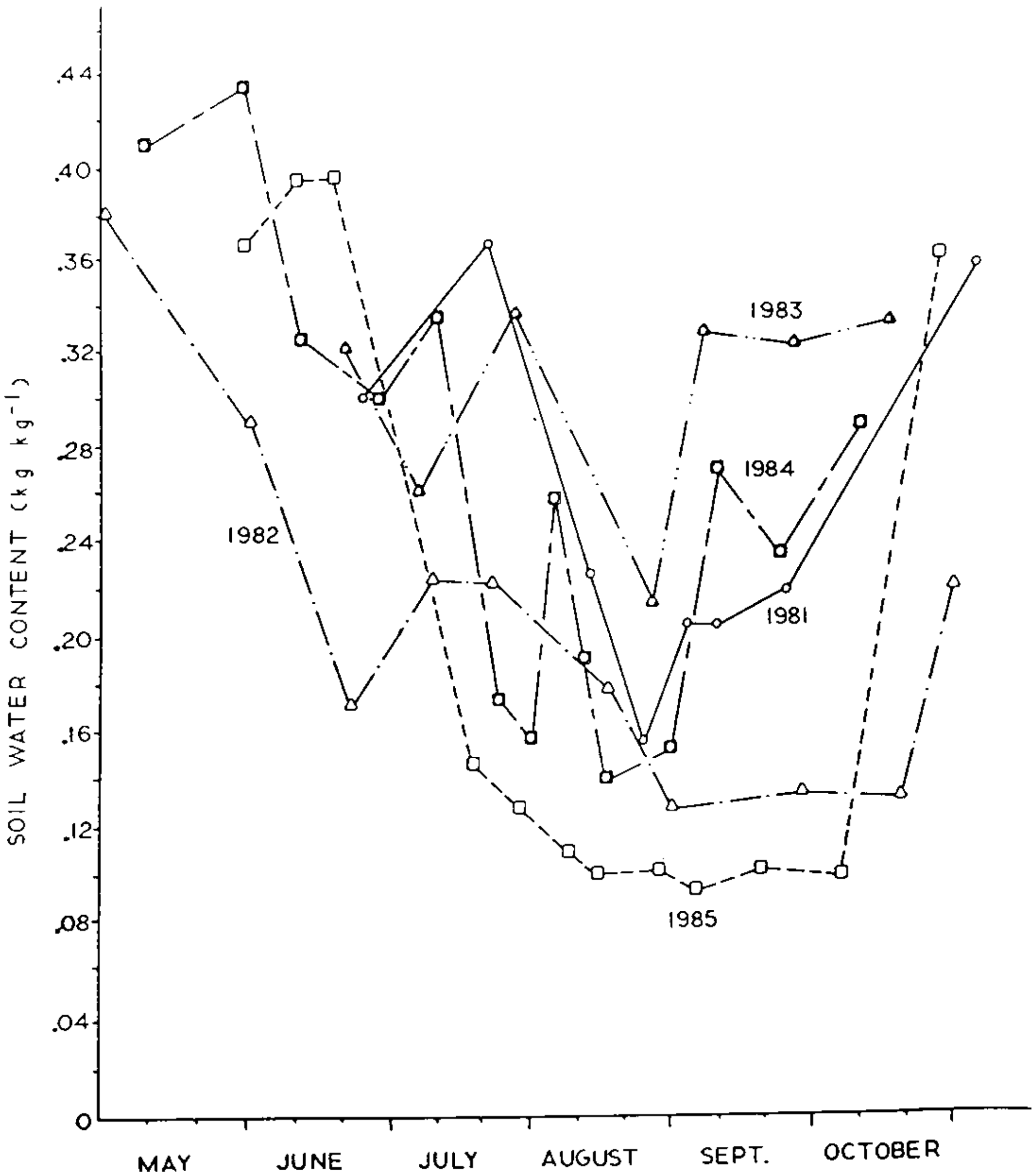

Figure 2. Changes in soil moisture content in the Whatcom series at 0.3 to 0.35 m during May through October 1981-1985.

measurements were taken thereafter at the woodland site to confirm the correlation.

The boundaries of the soil moisture control section are defined as the depths in a soil which will be moistened by 24-hour rainfall events of 25 and 75 mm, respectively (Soil Survey Staff 1975). Samples were taken at depths of 0.1 to 0.15 and 0.3 to 0.35 m, which is the approximate boundary of the soil moisture control section for soils of these textures (Soil Survey Staff 1975). The upper sample fits within the soil moisture control section of 0.06 to 0.19 m for the Whatcom soil as defined by the methods of Zobeck and Daugherty (1982).

Soils such as the Whatcom soils with dense substrata are recharged from the surface and dry out gradually as moisture is utilized during the growing season. Lateral water movement is unlikely in unsaturated conditions.

Results

If the soils are to meet the definition of the xeric moisture regime as defined in *Soil Taxonomy*, they must satisfy the three criteria: 1) they must be dry in all parts of the soil moisture control section to a tension more than 1.5 M Pa, 2) they must be dry for 45 or more consecutive days, and 3) they must be dry within the four months that follow the summer solstice in six or more years out of ten. In western Washington, if they dry for less time, they would be placed in a udic regime since they remain saturated in winter. The other mositure regimes (aquic, aridic, and ustic) are inappropriate due to the oxidizing conditions and high soil chroma, the amount of soil moisture, and the distribution of precipitation in the Whatcom soils, respectively.

The soils at the beginning of the sampling period each May were at approximately field capacity based on sampling of the profiles at this time and comparing the moisture content to the laboratory determined values at 33 kPa (Table 3). The moisture content decreased steadily until late August except for increases immediately after summer rainfall events, but reached the moisture value at 1.5 M Pa tension only in 1985, when a record summer drought occurred. The minimum water contents for the 1981-1985 sampling period were 15.6 kg kg^{-1}, 12.8 kg kg^{-1}, 21.4 kg kg^{-1}, 14.0 kg kg^{-1}, and 9.3 kg kg^{-1}. The only run of consecutive dry days during the five years was < 10 days in the upper horizon in 1985.

The 1.5 M Pa values determined by the National Soil Survey Laboratory were based on rewetted airdry samples (Dennis Nettleton, National Soil Survey Laboratory, personal communication). The amount of moisture held at this tension is significantly affected by allophane (Rousseaux and Warkentin 1976), which is common in Spodosols (Farmer 1982, Ross 1980). Whatcom soils contain about 2 percent allophane (Nettleton *et al.* 1985). Drying soils with allophane decreases their surface area, promotes shrinkage, and causes a decrease in water retention, CEC, and clay content as determined by mechanical analysis (Warkentin and Maeda 1974). Soils from Oregon that have high allophane content have been shown to hold 50 to 100 percent more water at 1.5 M Pa when analyzed moist than when rewetted from airdry (John Baham, Oregon State University, personal communication).

TABLE 3. Moisture values for the Whatcom series.

Depth (cm)	33 kPa (kg kg^{-1})	1.5 M Pa (kg kg^{-1})
0-23	60.9	9.5
23-33	31.6	8.5
33-41	31.8	8.9
41-51	20.8	6.3
51-66	21.9	9.3
66-89	26.7	9.3
89-150	15.9	12.6

In order to determine the long-term soil moisture regime, we must develop a relationship between soil moisture and climate based on the five sampling years in comparison to the 35 years on record. Although June and July 1981; July 1982; July and September 1983; June, August, and September 1984; and June 1985 were more than 10 percent above their respective monthly averages, the months of August 1981; June, August, and September 1982; August 1983; July 1984; and July and August 1985 were more than 10 percent below their respective monthly averages. Examining the records, we see that the mean for the five summers as well as the means of each of the five individual months (with three exceptions: July 1984, July and August 1985) are within one standard deviation of the respective means for the record period (Table 2).

The years 1981, 1983, and 1984 had above average precipitation and 1982 and 1985 were below average. In 1985 the soils dried to tensions > 1.5 M Pa for < 10 days, even though this was the longest rainless period on record. Based on Figure 1, the minimum moisture contents in which Whatcom soils are dry for 45 consecutive days in 1981, 1983, 1984, and 1985 in the 0.1 to 0.15 m layer are 30.6 kg kg^{-1}, 34.3 kg kg^{-1}, and 14.0 kg kg^{-1}, respectively. These are considerably higher than the 1.5 M Pa values of Table 3. The

1982 data are missing. The lowest value for the Whatcom soil for 1981-1985 was 9.3 kg kg^{-1} in the lower horizon and 9.6 kg kg^{-1} in the upper horizon in early September, 1985. If field moist samples were analyzed for 1.5 M Pa water content, the values would probably be higher, but even 50 percent higher would be insufficient to cause the soils to classify in the xeric moisture regime.

Whether by ground water recharge, higher field capacity than the lab-determined value due to layering, the average 40 mm per month summer precipitation, or the soil's ability to resist drying due to self-mulching, the moisture content remains above the 1.5 M Pa level or rises above it frequently enough to break any 45 day run. Two month stretches of less than 50 mm have occurred in 12 of the 35 years of record (Table 2), and in all but three of these 12 bimonthly periods, the previous month had more than a 10 percent overrun to build up the soil moisture storage before the dry period.

Since 1930, approximately half of each of the months June, July, August, and September received more than 110 percent of the respective average precipitation. Two-thirds of any two consecutive month period had more than 10 percent overruns and more than 80 percent of three consecutive months a 10 percent overrun.

Determining how likely a soil is to dry out for 45 consecutive days in 6 or more years out of 10 is difficult to determine without long-term analysis. However, upon examining the 35 years of precipitation records and comparing this with the precipitation during the study period, none had less July and August precipitation than 1985, and only 4 years (or 11%) had drier four-month totals; only in these years could the soils have dried to the 1.5 M Pa tension for 45 consecutive days, certainly less than the required minimum of 6 or more years out of 10, specified for the xeric moisture regime.

Conclusions

Based on a comparison of precipitation records for 1981-1985 with previous years, the climate during the study period was within one standard deviation of precipitation means. If the assumption is valid that the corresponding soil moisture conditions are also typical, we are led to the conclusion that the Whatcom series does not exceed 1.5 M Pa tensions for the required 45 consecutive day period for 6 or more years out of 10. The soil moisture reaches these tensions only under unusual circumstances, which occur much less than 60 percent of the time. Thus, these soils appear to stay moist long enough (i.e., they don't dry out long enough) to be classified in a udic, rather than a xeric moisture regime.

Using Whatcom soils to represent other soils in western Washington which have been classified in the xeric moisture regime, it appears that if soils in this area were intended to be "xeric" to differentiate them taxonomically from udic soils in the Midwest, the definition of the xeric moisture regime needs to be changed to include them. This could be done by reducing the number of consecutive dry days or lowering the tension at which they are considered dry.

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