

Relation between Size Fraction Component of Soil and Soil Water Retentivity Especially Water Content in the Green Space Irrigation

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ABSTRACT

This paper explains the method to estimate the soil water retentivity or the available water capacity by using a sand mass fraction measurement which can be easily achieved by sieving. The regression analysis on 60 soil samples in Japan showed the wetness on retentivity curve can be estimated from the size fraction component of soil. Among the size fraction component of soil, the best relation was obtained with sand, correlation coefficient being 0.8. When the wetness was over pF 2.5, an improvement of relation was observed with every soil size fraction. On the other hand, the wetness differences at several pF ranges versus soil size fraction relationship was examined and the best correlation coefficient was 0.6, which was worse than that obtained in wetness estimation. The factor that deteriorates the relation seems to be included in the low pF soil water range. Nevertheless, since the relations were statistically significant upon the analysis of variation at 1 % significance, the results of this study are applicable for the simple estimation of available water capacity in situ.

Introduction

For green space construction, an irrigation system to maintain green growth is not usually included in Japan. Owing to a lot of rain in this country, the plants can usually grow without an irrigation system. Even in the case of no irrigation system we have to consider the available water capacity of the soil concerned so that soil design can cover the drought resistance because urban districts have a tendency to become drier recently and sometime hard drought occurs such as in 1994.

There are many kinds of soils classified in sand, loam, silty loam, silty clay loam, clay loam and clay in this country. These soil textures are usually determined by mechanical analysis. On the other hand, soil water retentivity for such soils are fundamentally determined by the soil texture, soil structure and clay minerals. However it is

considered that soil texture influences on the retentivity mostly. Then if we can determine the soil water retentivity from the soil component fraction measurement, it is very convenient to the workers in situ. Such works were practiced in agronomical field. Umeda et al. [3] examined this relation by using the samples in the central Hokkaido district and wetness on retentivity curve is well correlated with the size fraction component of soil. Then they concluded the use of silt plus clay fraction can estimate the "available water capacity" in which they defined the wetness difference between at pF 1.7 as the field capacity and at pF about 2.7 as the depletion of moisture content for optimum growth. In this paper we expand this relation to the districts beside Hokkaido.

Materials and Method

Sixty soil samples are collected from the wide

Table 1 List of Sample

Sample No	Site (Prefecture)	(Region)	Texture	Density (g/cm ³)	Sand (wt%)	Silt (wt%)	Clay (wt%)
1	Miyagi	Natori C.	SL	2.61	51.74	32.26	16.00
2	Miyagi	Natori C.	CL	2.53	22.38	48.62	29.00
3	Miyagi	Natori C.	SL	2.64	65.67	21.33	13.00
4	Miyagi	Iwanuma C.	SiCL	2.62	15.45	55.55	29.00
5	Miyagi	Iwanuma C.	SiL	2.57	31.93	50.07	18.00
6	Miyagi	Murata T.	SiL	2.68	32.40	50.60	17.00
7	Fukushima	Tomioka T.	SiCL	2.50	13.69	61.31	25.00
8	Fukushima	Tomioka T.	SiCL	2.45	14.61	63.39	22.00
9	Fukushima	Tomioka T.	SiCL	2.46	18.77	60.23	21.00
10	Fukushima	Tomioka T.	SiCL	2.54	20.32	52.68	27.00
11	Fukushima	Tomioka T.	L	2.61	48.99	39.51	11.50
12	Fukushima	Tomioka T.	SiL	2.49	23.46	61.54	15.00
13	Fukushima	Tomioka T.	SiL	2.51	37.30	58.70	4.00
14	Tochigi	Sano C.	CL	2.64	43.95	30.05	26.00
15	Tochigi	Sano C.	CL	2.56	38.45	31.55	30.00
16	Tochigi	Sano C.	SL	2.53	27.62	54.18	18.20
17	Tochigi	Sano C.	L	2.61	37.75	44.25	18.00
18	Tochigi	Sano C.	CL	2.60	34.62	39.38	26.00
19	Ishikawa	Kanazawa C.	SL	2.66	79.43	10.47	10.10
20	Ishikawa	Kanazawa C.	C	2.55	15.00	48.20	36.80
21	Ishikawa	Matsuto C.	CL	2.63	48.00	32.00	20.00
22	Ishikawa	Matsuto C.	C	2.55	26.18	39.82	34.00
23	Fukui	Miyazaki V.	CL	2.61	46.97	23.03	30.00
24	Fukui	Miyazaki V.	CL	2.55	35.20	34.80	30.00
25	Fukui	Takeo C.	CL	2.59	35.23	34.77	30.00
26	Fukui	Takeo C.	SL	2.67	69.78	14.42	15.80
27	Fukui	Miyazaki V.	L	2.47	41.52	46.68	11.80
28	Shimane	Gotsu C.	L	2.70	41.00	40.20	18.80
29	Shimane	Gotsu C.	CL	2.67	42.00	31.40	26.60
30	Shimane	Gotsu C.	CL	2.63	25.50	46.60	27.90
31	Shimane	Gotsu C.	C	2.63	37.00	31.20	31.80
32	Shimane	Gotsu C.	SL	2.68	76.70	9.80	13.50
33	Shimane	Oda C.	SiCL	2.55	15.40	56.10	28.50
34	Shimane	Kamo T.	SL	2.64	67.55	22.45	10.00
35	Shimane	Kamo T.	SL	2.64	62.20	19.30	18.50
36	Shimane	Kamo T.	SL	2.64	77.30	14.20	8.50
37	Shimane	Kamo T.	SL	2.68	70.20	17.60	12.20
38	Shimane	Kamo T.	SL	2.68	79.00	9.60	11.40
39	Shimane	Kamo T.	S	2.68	87.60	2.40	10.00
40	Shimane	Hirose T.	SL	2.66	56.80	29.50	13.70
41	Shimane	Hirose T.	SL	2.61	60.70	23.00	16.30
42	Shimane	Hirose T.	S	2.58	89.20	3.30	7.50
43	Shimane	Hirose T.	SL	2.62	76.70	14.30	9.00
44	Shimane	Matsue C.	SiCL	2.69	3.90	68.10	28.00
45	Shimane	Koryo T.	S	2.67	75.10	19.90	5.00
46	Shimane	Izumoshi C.	SL	2.64	61.40	26.10	12.50
47	Shimane	Matsue C.	C	2.70	16.40	48.60	35.00
48	Kagawa	Takamatsu C.	SL	2.56	68.79	14.21	17.00
49	Kagawa	Takamatsu C.	L	2.60	42.82	47.00	10.18
50	Kagawa	Okawa T.	CL	2.72	44.89	34.11	21.00
51	Kagawa	Takamatsu C.	CL	2.72	38.91	34.09	27.00
52	Saga	Ushizu T.	C	2.57	15.05	41.95	43.00
53	Saga	Kohoku T.	C	2.56	14.00	43.00	43.00
54	Saga	Kohoku T.	SiC	2.56	1.82	59.68	38.50
55	Saga	Kohoku T.	SL	2.60	69.71	19.29	11.00
56	Saga	Ushizu T.	SCL	2.78	50.12	26.98	22.90
57	Saga	Ushizu T.	CL	2.72	29.05	44.95	26.00
58	Saga	Ariake T.	SiL	2.43	31.66	51.54	16.80
59	Saga	Kohoku T.	C	2.43	9.00	54.00	37.00
60	Saga	Kohoku T.	C	2.46	1.16	54.84	44.00

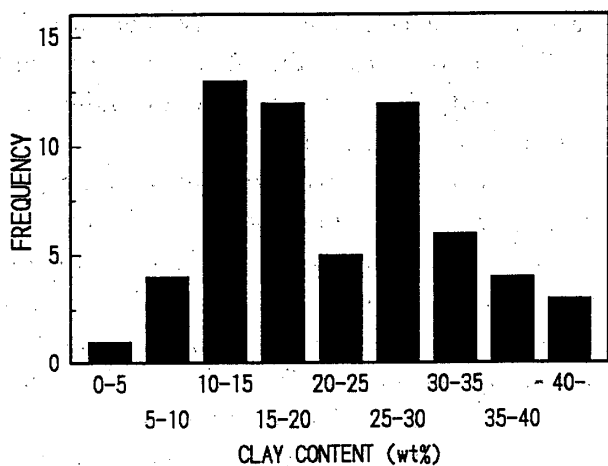


Fig.1 Distribution of Soil Samples in Reference to Clay Content

districts of the country except Hokkaido as listed in Table 1. These are from 8 prefectures or 22 regional sites and classified 17 samples as sandy loam, 13 as clay loam, 8 as clay, 7 as silty clay loam, 5 as silty loam, 5 as loam and 5 as others. Fig. 1 shows the distribution of samples according to clay fraction content. And the average texture for all sample is classified in CL. The particle size distribution is determined by the mechanical analysis of Japanese Industrial Standard or a hydrometer and sieving method for soil mechanics. The upper size limit for component soil is 2000 micrometers for sand, 75 for silt and 5 for clay. Samples are pretreated in air-drying condition and after crushing particle density of them were measured. The aqueous solution including Sodium cation (Na^+) was added to the soil particle solutions as dispersing agent. The soil water retentivity was examined by both the suction plate and the centrifugal dehydrometer. Each method was depending upon the range of soil water potential. Suction plate is used for the range below pF 2 (-9.8J/kg) and the centrifuging for the range over this value. Samples for the retentivity test are prepared to immerse themselves under the water table and wait for 24 hours. The time required for soil water equilibrium is ambiguous but takes also 24 hours.

Results and Discussion

Fig. 2, 3 and 4 show relation between size

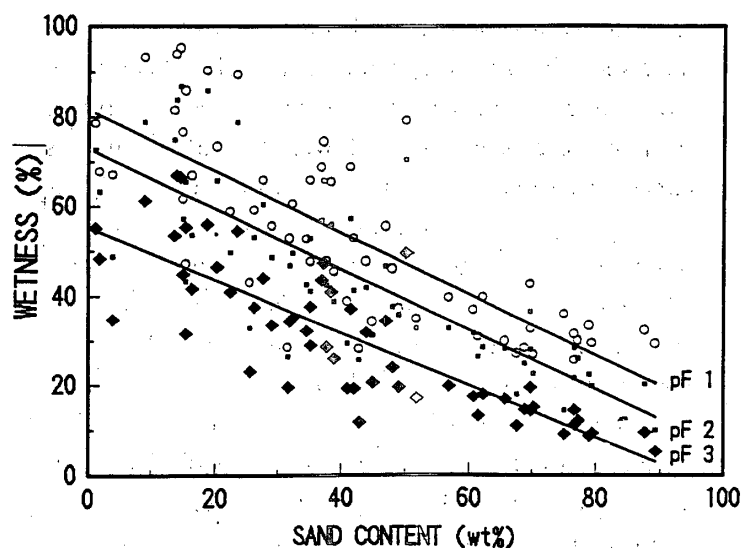


Fig.2 Relation between Sand Content & Wetness

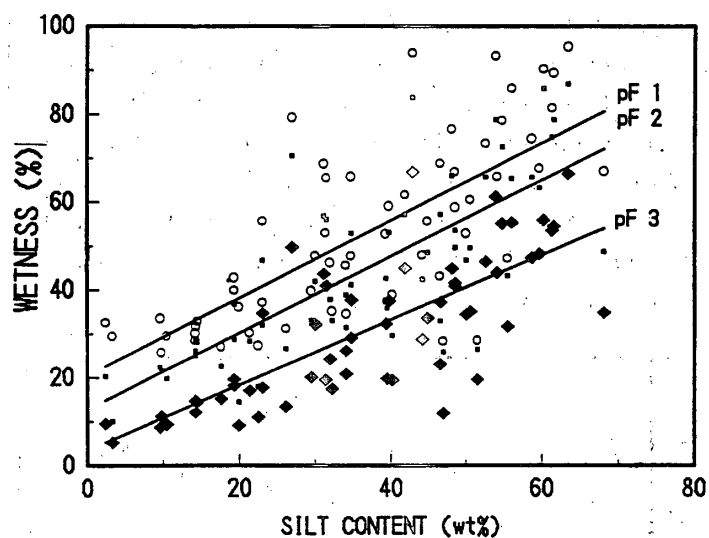


Fig.3 Relation between Silt Content & Wetness

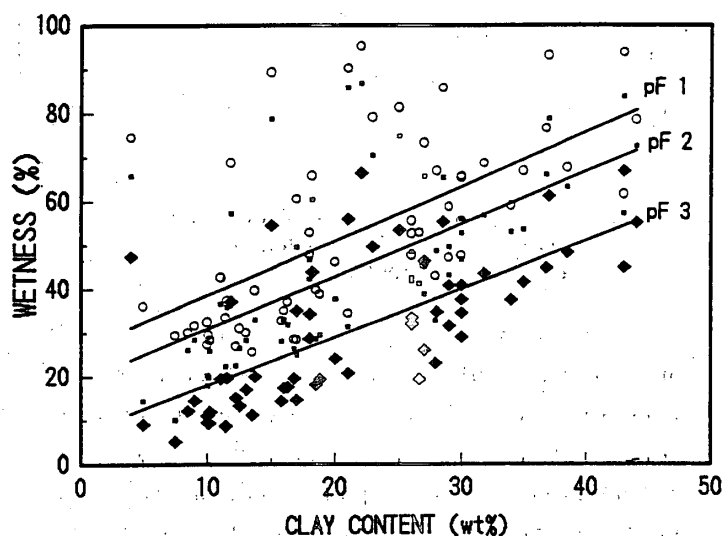


Fig.4 Relation between Clay Content & Wetness

fraction component of soil and soil water wetness at a specified soil water potential (pF). Each fraction has relation almost linearly to soil wetness. And wetness is higher at lower pF value, that is expected because the wetness at lower pF is higher than at upper pF value on soil water retentivity. Sand in Fig. 2 shows inverse correlation but others positive correlations. Another feature is the scattering of data. Data of wetness at pF 1 scatters more than at other pF values.

Correlation coefficients between mass fraction of soil component and wetness at specified pF values are shown in Fig. 5. Values increase somewhat abruptly near pF 2 in any of soil components which show some factor that makes linearity of regression line worse is included at higher pF. Relation between correlation coefficient and wetness at specified pF in clay component shows that the rise of coefficients is somewhat slower than in other components. In any case correlation becomes better in higher pF region. As a result the comparison among soil components shows that correlation in sand is the best, medium in silt and the worst in clay.

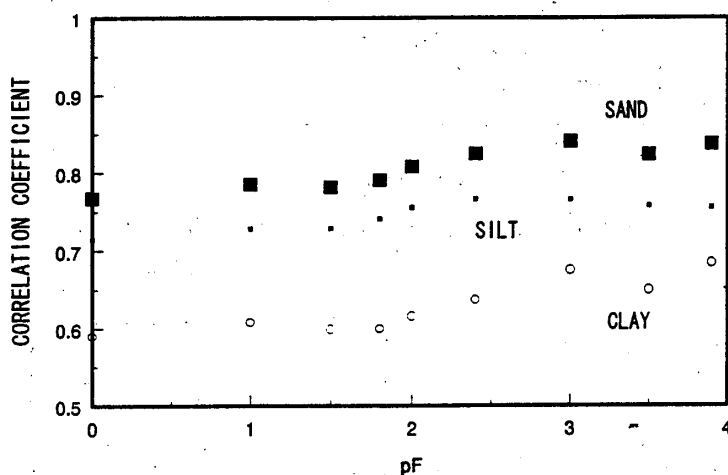


Fig.5 Correlation Coefficient between Mass Fraction of Soil Component and Wetness at Specified pF

The scattering in clay results from the dependency of retentivity on complicated clay mineral behaviors. On the contrary the water retention by the soil particles less than that classified in silt correlates best with component soil mass fraction as well as best correlation in sand. It is because

all the soil component sum is always constant in 100%. This results show the estimation of soil water retentivity is approximately available by use of sand fraction measurement.

On the other hand, we are much concerned about relation of soil water difference versus soil fraction because of irrigation problem. Available water capacity is generally defined as the wetness difference between the field capacity (FC) and the permanent wilting point (PWP) [2]. This is considered as the amount of water that soil can supply to plants. However time consuming measurements are required to decide this value. If we get this only by one of the soil component fractions, it will become more convenient in situ, even if some errors are included. Both FC and PWP are usually considered as constants, but the definitions are somewhat different or change in countries. In case of Japan FC is defined as wetness at pF 1.5-2.0 (-3.1~-9.8J/kg) or pF 1.8 (-6.2J/kg), and PWP as at pF 4.2 (-1.55kJ/kg). And the lowest limit of moisture content for optimum growth is defined as pF 3 (-100J/kg) to make the crop production maximum in place of using PWP [2]. This definition may be exceptional because of much rain and Japanese agronomy requirements. In case of United States FC is defined as 5~10kPa (-5~-10J/kg) for coarser-textured soil, 33kPa (-33J/kg) for medium-textured soil and 50kPa (-50J/kg) for finer-textured soil. And also PWP is defined as 15bar (-1.5kJ/kg) [1]. Therefore "available water" is a difference between two soil water constants defined in different ways. In this study the wetness on retentivity over pF 2.5 is well correlated with sand fraction. So if we took the wetness difference from this result, correlation of

Table 2 Correlation Coefficients between Size Fraction Component of Soil and Wetness Difference

Δw	Sand	Silt	Clay	Si+Cl
pF 2-3	0.4319	0.4754	0.2088	0.4319
pF 1.8-3	0.4076	0.1973	0.1973	0.4076
pF 1.5-3	0.3643	0.392	0.191	0.3643
pF 2-3.9	0.6264	0.6245	0.4118	0.6264
pF 1.8-3.9	0.6034	0.6042	0.3924	0.6034
pF 1.5-3.9	0.5897	0.5835	0.3953	0.5897

Δw (pF2-3) designates the difference between the wetnesses at pF2 and pF3

wetness difference would be expected to be worse. Table 2 shows representative results of regression analysis for size fraction component of soil vs. wetness difference. The results of sand fraction and then silt plus clay fraction are best in all combination. In case of fixed pF end as a high limit we have a tendency of better correlation with higher pF end as a low limit. And good results are obtained at pF 3.9 from the comparison between 3 and 3.9 as a high pF limit, and the correlation coefficient are improved by about 0.2. So it is preferable to take higher pF limits to improve correlation.

In case of pF 2-3 and pF 2-3.9 correlation about wetness difference (Δw) versus soil component fraction is shown in Fig. 6 and Fig. 7, respectively.

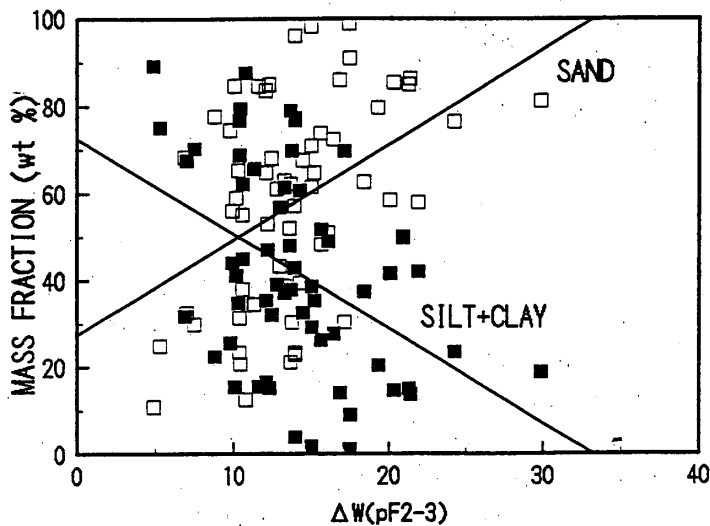


Fig.6 Relation between Mass Fraction And ΔW

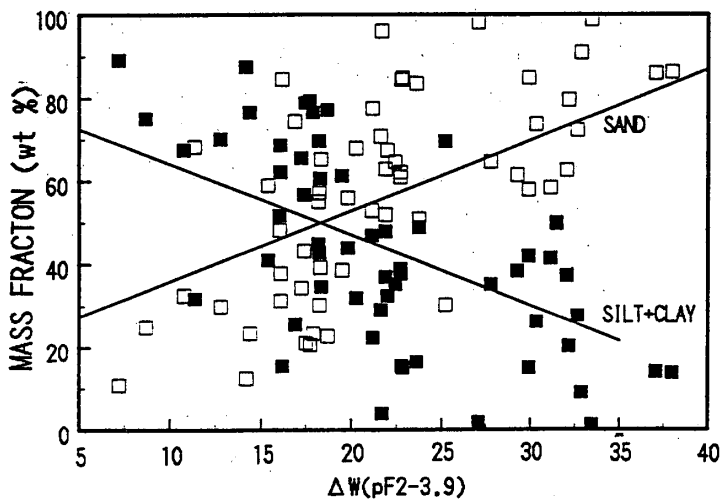


FIG.7 Relation between Mass Fraction and ΔW

Table3 ANOVA of Sand Fraction and Wetness Difference

(1) Sand fraction VS ΔW (pF 2-3)

Factor	Square Sum	Degree of Freedom	Unbiased Variance	Variance Ratio
Regression	6,078.86	1	6078.86	13.3
Residual	26,502.4	58	456.94	
Total	32,581.2	59		

F (0.05) = 4.00 [F(0.01) = 7.09] < Variance ratio → Significant

(2) Sand fraction VS ΔW (pF 2-3.9)

Factor	Square Sum	Degree of Freedom	Unbiased Variance	Variance Ratio
Regression	12,782.9	1	12,782.9	37.45
Residual	19,789.3	58	341.35	
Total	32,581.2	59		

F (0.05) = 4.00 [F(0.01) = 7.09] < Variance ratio → Significant

Δw (pF2-3) designates the difference between the wetnesses at pF2 and pF3

And also the result of analysis of variance in one-way layout is shown in Table 3. Every result shows statistical significance. Wetness difference is correlated well with sand mass fraction or silt plus clay fraction in spite that the definition of available water capacity has some problem. This means that the specified wetness difference can be estimated by simple sand fraction measurement. It is sure that some errors are included in this method, but we can roughly estimate this difference easily in situ.

Conclusion

From the simple measurement of sand mass fraction like sieving the water retentivity can be roughly estimated, in spite that linearity below pF 2.5 becomes somewhat worse in the wetness versus sand mass fraction relationship. And also the wetness difference can be estimated by the sand mass fraction measurement which has a possibility to estimate "available water capacity". However the correlation of wetness difference becomes worse than the estimation of wetness itself. So it is preferable to take both pF limits as possible as high. And if "available water capacity" can be defined to higher pF limits, this method can estimate it with comparatively high accuracy. The possibility of estimation by sieving sand and the

deterioration of correlation coefficient in wetness difference estimation are not referred by Umeda et al. [3].

Reference

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緑地灌漑における土の粒径成分と保水特性上の含水比との関係に関する研究

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摘 要

本研究は粒度分析より得られる土の粒径成分と保水特性の関係を調べ、粒径成分から特性上の含水比ならびに含水比差を推定する際の問題点を明らかにした。その結果、近似的にはあるが、「有効水分量」を推定することが可能であることを示した。北海道地区を除く全国60地点の試料を用い、粒度分析ならびに保水特性測定を行い、回帰分析にかけた。特定の水分ポテンシャル(pF)での含水比と粒径成分との関係は、低pFから高pFに向かって相関が良くなり、その改善はpF2前後で急に良くなる。このことは、低pF水分保水に様々な変動要因が含まれていることを示唆する。一方、粒径成分中、もっとも相関の良かったものは、砂分であり、その値は約0.8まで達した。一方、特定のpF域における水分量差と砂分と

の相関は、もっとも良い相関の場合でも0.6程度であった。すなわち、水分量差の場合は、水分量自体の推定に比べ相関が悪くなることに注意しなければならない。含水比そのものの推定より、相関が悪くなるが、得られた回帰分析結果は一元配置の分散分析によって1%の有意水準で有意である。土の有効水分量には目的に応じて、また国によって様々なポテンシャル範囲を採用している。本研究の成果によれば、できるだけ高pFの範囲に定義される水分量差が採用できる場合には相関がよくなる。砂分を基本とした推定が可能になるということは砂分以外の細粒分と保水性ならびに水分量差あるいは有効水分との相関が良いということであり、その量の決定に当たっては簡単な篩別分析によってこれらの量が決定可能ということである。したがって、現場における簡便な有効水分の決定が可能になることを意味する。