DESIGN PARAMETERS OF MICROPILE IN PERMAFROST SANDY GROUND

Changho Choi[1], Joonyong Lee[2], Tae-Hyung Kim[3], Sung-Gyu Ko[4]

ABSTRACT

In this paper, a geotechnical design parameter for micropiles in permafrost ground is discussed. It is known that the bearing capacity of pile in permafrost ground conditions is designed based on the adfreeze bond strength between the surrounding soil and pile perimeter in frozen ground. This indicates that the adfreeze bond strength is a primary design parameter. In this study, both shear strength and adfreeze bond strength tests were carried out using the direct shear testing method to analyze the quantitative relationship between shear strength and adfreeze bond strength for sandy soil. Then, a proportional coefficient, r_s, is suggested from the relationship between shear strength and adfreeze bond strength. Because the coefficient r_s is obtained in various temperature and pile surface roughness conditions, it can be used as a foundation design parameter in frozen sandy ground.

Keywords: Micropile, frozen ground, adfreeze bond strength

1. INTRODUCTION

The external loading condition for pile in frozen soil changes with the season, as permafrost or perennially frozen ground in cold regions experiences annual thawing and refreezing with the change of seasons. Therefore, the characteristics of loading conditions in summer and winter should be considered in the design of pile foundations in frozen soils. Typically, in unfrozen soils the bearing capacity of pile is governed by both skin friction and end bearing capacity, while in frozen soils the bearing capacity of pile foundations is only governed by skin friction force (Freitag et al., 1997). Skin friction force, which arises from the interaction between the pile and the frozen soil, is defined as the adfreeze bond strength, one of the most important key parameters for the design of piles in frozen soils. Adfreeze is a shear bond between the pile shaft and the adjacent frozen soil skeleton (Cuthbertson-Black, 2001). Since the 1960s, multiple studies have been carried out to determine the adfreeze bond strength for the design of piles in frozen soils.

It is not an easy task to determine the adfreeze bond strength, since its characteristics in cold regions are governed by intrinsic material properties such as grain size, ice and water content, air bubbles, and by externally imposed testing conditions such as temperature, freezing time, and rate of loading. There are two major

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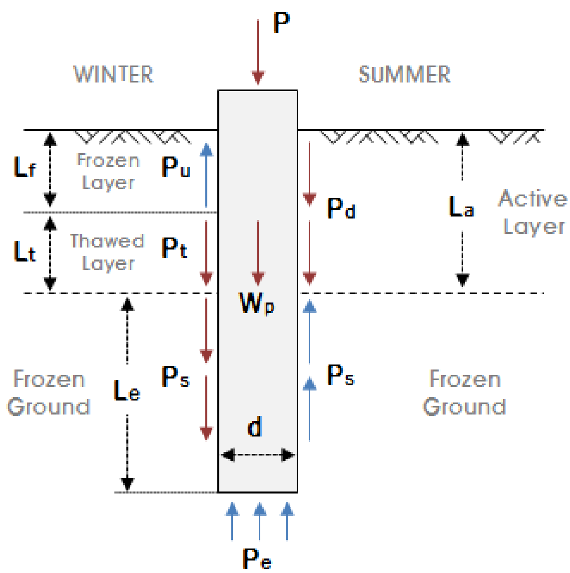
types of approaches to determine the adfreeze bond strength. One is to directly measure the adfreeze bond strength using experimental equipment, and the other is to predict adfreeze bond strength based on the shear strength of frozen soils (Sanger, 1969; Linell and Lobacz, 1980; Weaver and Morgenstren, 1981; Fang, 1991; Bowles, 1996). In particular, many geotechnical researchers are interested in the latter approach, since the shear strength characteristics with varying different temperature conditions can be considered when determining adfreeze bond strength.

This paper describes the test equipment used to measure the shear strength of frozen soils and adfreeze bond strength between frozen soils and aluminum with varying temperature conditions and normal stress inside a large-scale freezing chamber, and analyzes the relationship between the adfreeze bond strength and shear strength of frozen soils. Even though aluminum is not a common pile material, it was used for this study because it is easy to process the various roughness conditions.

2. BACKGROUND

As shown in Fig. 1, cold regions are typically subdivided into seasonal frost (active layer) and permafrost (frozen ground) areas depending on whether the ground is frozen seasonally or remains frozen for more than two years. Loading conditions of pile foundations are typically subdivided into summer and winter conditions due to the difference in the frost penetration depth. Therefore, pile foundations in cold regions should be designed to be stable with the changes in loading conditions with the seasons. The most important factors in the evaluation of bearing capacity and upward force of pile foundation in summer and winter conditions are the upward skin friction force of permafrost zone, P_s and the upward skin friction force of frozen layer in the active zone, P_u, respectively, which are shown in Fig. 1. P_s and P_u are generally produced by the adfreeze bond strength, which arises from the interaction between pile and frozen soils.



$P_u (=\pi d L_f) \leq P + W_p + P_t + P_s$

L_f : depth of frozen layer in active zone
L_t : depth of thawed layer in active zone
L_e : depth of permafrost zone
W_p : weight of foundation
P : downward load
P_t : downward skin friction force of thawed layer in active zone
P_s : downward skin friction force of permafrost zone
P_u : upward skin friction force of frozen layer in active zone
τ_u : adfreeze bond strength of frozen layer in active zone

$P + W_p + P_d \leq P_s (=\pi d L_e \tau_a)$

L_a : depth of active layer
L_e : depth of permafrost zone
W_p : weight of foundation
P : downward load
P_d : downward skin friction force of active layer
P_s : upward skin friction force of permafrost zone
τ_a : adfreeze bond strength of active layer

Figure 1. Loading conditions of pile foundation in frozen ground (Phukan, 1985)

The adfreeze bond strength is the basic strength parameter for the design of piles in cold regions, and can be expressed by the Mohr-Coulomb strength equation as a linear function of the normal stress at failure as shown in Eq. (1).

$$\tau_a = a + \sigma \tan \delta \quad (1)$$

where τ_a is the adfreeze bond strength, a is the cohesion at the soil pile/interface, δ is the friction angle at the soil/pile interface, and σ is the normal stress acting along the soil/pile interface

The methods that can be used to determine the adfreeze bond strength for design of pile foundations in cold regions can be broadly subdivided into direct measurement in the lab or field and prediction based on the shear strength characteristics of frozen soils. In particular, many researchers have been interested in the latter method. Weaver and Morgenstern (1981) suggested the relationship between the adfreeze bond strength and the shear strength of frozen soil, as shown in Eq. (2).

$$\tau_a = r_s \times \tau_f \quad (2)$$

where τ_a is the adfreeze bond strength, r_s is the proportional coefficient for roughness/pile surface parameter, and τ_f is the shear strength of frozen soils. Weaver and Morgenstern (1981) summarized the proportional coefficient r_s for common pile materials as shown in Table 1. It is noted that the surface roughness of materials produces the varieties of proportional coefficients r_s.

Table 1. Proportional coefficient r_s for predicting the adfreeze bond strength(Weaver and Morgenstern, 1981).

Material Type	r_s
Steel	0.6
Concrete	0.6
Uncreosoted Timber	0.7
Corrugated Steel	1.0

The shear strength of frozen soils in Eq. (2) can also be expressed using the Mohr-Coulomb strength equation, as shown in Eq. (3).

$$\tau_f = c + \sigma \tan \phi \tag{3}$$

where *c* is the cohesion and *Φ* is the internal friction angle. Notably, Sayles(1973) suggested the shear strength equation of frozen soils has a parabolic shape when the ice content is greater than 25% and the porosity is greater than 37%, as shown in Eq. (4).

$$\tau_f = (c + b \cdot \sigma)^{0.5} \tag{4}$$

where $c^{0.5}$ is the cohesive force at zero normal stress and *b* is a function of the internal friction angle.

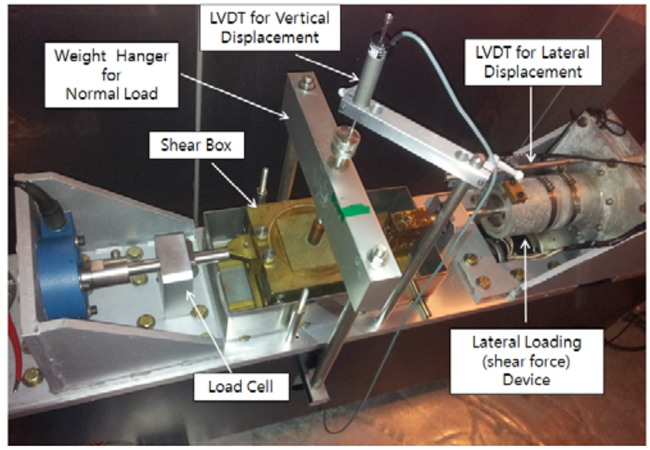
3. TEST PROCEDURE AND RESULTS

In this study, the large-scale freezing chamber and direct shear apparatus were used for measuring the adfreeze bond strength, as shown in Fig. 2. The large-scale freezing chamber is 2000mm(W)×3000mm(L)×2500mm(H), and can control temperature down to –20 degrees Celsius through a temperature distribution of ±1 degree Celsius. The direct shear apparatus located inside of the freezing chamber can be operated at –30 degree Celsius conditions. In this study, Joomoonjin sand and weathered granite soil were used for testing. Table 2 shows the physical properties of two test materials and Figure 3 shows the grain size distribution curves of two test materials.

Test specimens of Joomoonjin sand and weathered granite soil were prepared with relative densities of 77% and 76%, respectively, and the degree of saturation of two test specimens were 100% and 67%, respectively. Direct shear tests to measure the shear strength of frozen soils and adfreeze bond strength tests were carried out with shear displacement rate of 0.5mm/min under three normal stress conditions of 100kPa, 200kPa, and 300kPa until the horizontal displacement reached approximately 15% of specimen width or until the adfreeze bond strength became constant, whichever occurred first.

Four freezing temperatures of 0, -2, -5, -10 degrees Celsius were applied for the Joomoonjin sand, whereas five freezing temperatures of 0, -2, -5, -10, -15 degrees Celsius were applied for the weathered granite soil. Also, each direct shear test to measure both shear strength of frozen soils and adfreeze bond strength were carried out after a 24-hour freezing period. For the measurement of adfreeze bond strength, the aluminum was inserted in the lower part of the direct shear box instead of the soils, as shown in Fig. 4.

(a)Freezing chamber



(b)Direct shear apparatus

Figure 2. Test equipment

Table 2. Physical properties of test materials

	G_s	e_{max}	e_{min}	D_{50}	C_u	C_c	USCS
Joomoonjin Sand	2.65	0.992	0.596	0.56	1.53	0.94	SP
Weathered Granite	2.67	1.227	0.418	0.71	6.07	1.29	SW

Table 3 and Fig. 5 show the results of the tests of shear strength of frozen soils and adfreeze bond strength with varying freezing temperatures and normal stresses for each soil type. The shear strength and adfreeze bond strength when using Joomoonjin sand at 0 degrees Celsius were lower than when using weathered granite soil. On the other hand, the shear and adfreeze bond strengths when using Joomoonjin sand become higher than those of weathered granite soil due to higher water content as the temperature becomes lower. The strength characteristics increase as the temperature decreases for both soils, and tend to increase as normal stress increases, as shown in Table 3 and Fig. 5. Also, a wider discrepancy between shear strength and adfreeze bond strength is observed as the freezing temperature becomes lower.

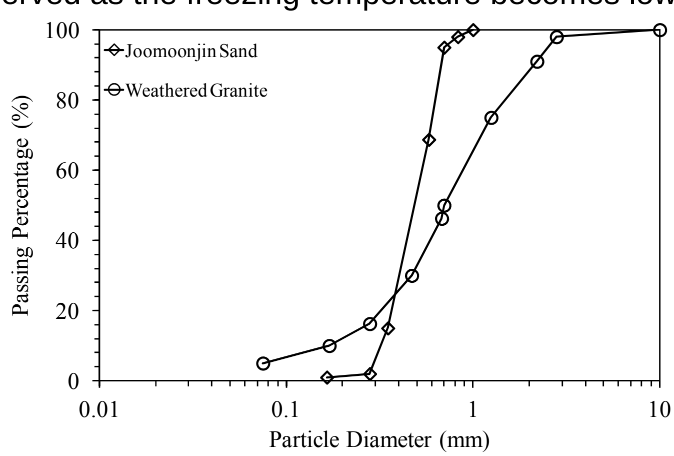


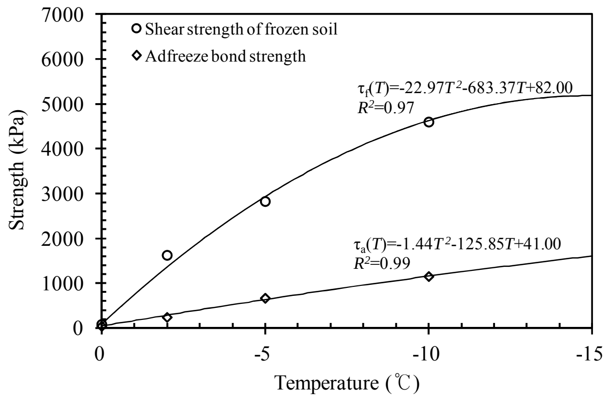
Figure 3. Grain size distribution curves of test materials

Figure 4. Picture of Aluminum in the lower part of direct shear box

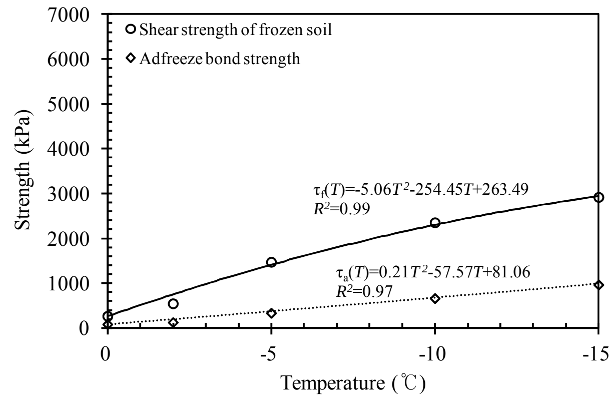
Table 3 Results of test of shear strength and adfreeze bond strength

Freezing Temperature(℃)	Normal Stress(kPa)	Joomoonjin Sand		Weathered granite soil	
		Shear Strength(kPa)	Adfreeze Bond Strength(kPa)	Shear Strength(kPa)	Adfreeze Bond Strength(kPa)
0	100	82	42	263	81
0	200	146	69	291	137
0	300	236	88	355	210
-2	100	1624	239	543	123
-2	200	1781	323	667	231
-2	300	1941	430	863	298
-5	100	2824	665	1469	330
-5	200	3160	816	1690	389
-5	300	3519	915	1912	464
-10	100	4596	1150	2350	660
-10	200	5137	1294	2577	864
-10	300	5456	1445	2921	895
-15	100	-	-	2916	961
-15	200	-	-	3050	1056
-15	300	-	-	3293	1105

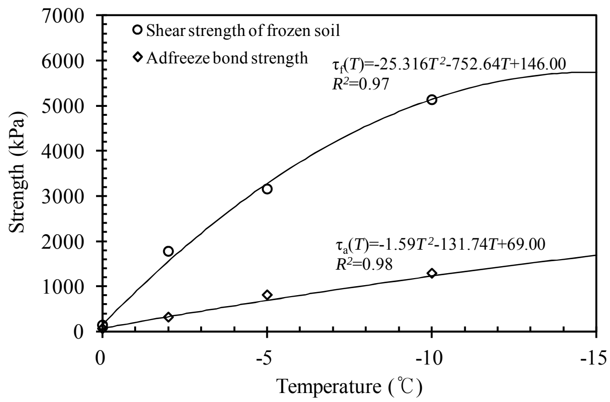
Figure 6 shows the proportional coefficient r_s of adfreeze bond strength to shear strength of frozen soils obtained from fitting curve in each condition of Fig. 5. The coefficient decreases at temperature range between 0 and -5 degrees Celsius, and the ratio becomes constant as temperature decreases below -5 degrees Celsius. This indicates that the temperature condition has an influence on the proportional coefficient in initial freezing conditions. According to previous studies, the ratio between adfreeze bond strength and shear strength of frozen soil is not affected by temperature conditions, and is maintained as constant over the whole freezing temperature range (Weaver and Morgenstern, 1981). However, the previous study has a limit, as shown in our results. Therefore, careful analysis is needed to evaluate the proportional coefficient between adfreeze bond strength and shear strength of frozen soils, especially in initial freezing temperature conditions.



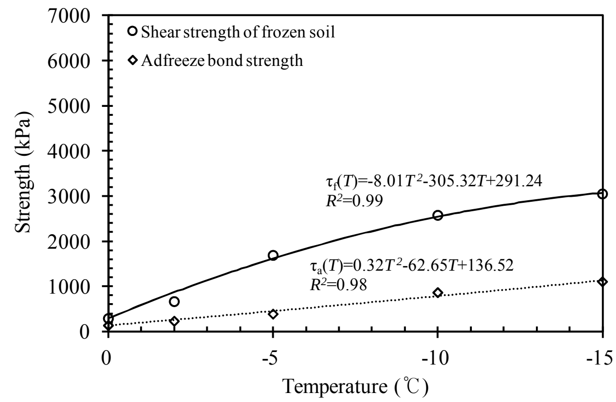
(a)100kPa(Joomoonjin sand)



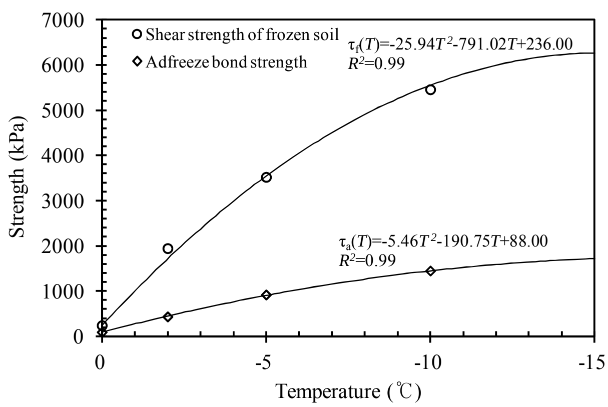
(d)100kPa(Weathered granite soil)



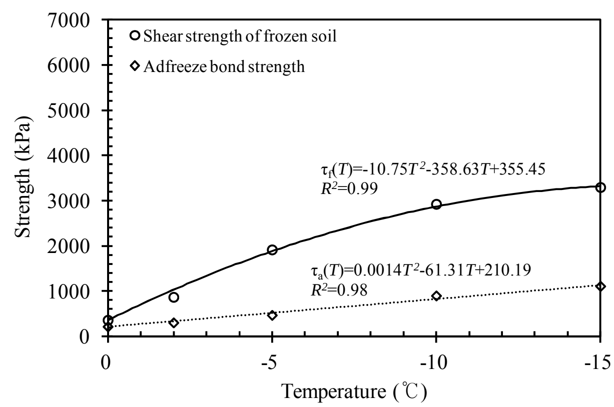
(b)200kPa(Joomoonjin sand)



(e)200kPa(Weathered granite soil)



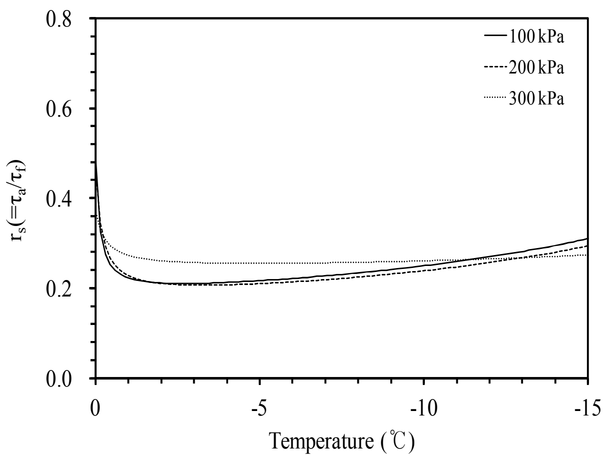
(c)300kPa(Joomoonjin sand)



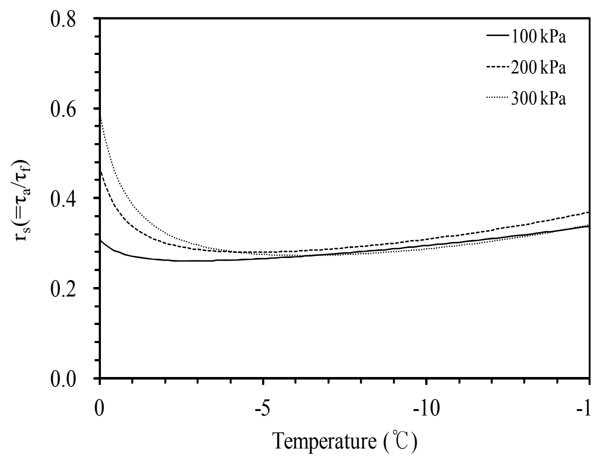
(f)300kPa(Weathered granite soil)

Figure 5. Results of tests of two materials with varying normal stress

Figure 7 shows the comparison of the proportional coefficient between this study and previous studies at -2 degrees Celsius. As shown in Fig. 7, the proportional coefficient values at -2 degrees Celsius show the discrepancy between this and previous studies, since the shear strength of frozen soils and adfreeze bond strength are sensitive to various factors such as soil type, pile type, external testing conditions, and so on. Based on Fig. 7, it is noted that the proportional coefficient must be chosen with care. Ladanyi and Theriault (1990) provide a conservative design parameter, while Weaver and Morgenstern (1981) provide a much more aggressive design parameter with respect to bearing capacity. In this respect, this study provides better appropriate coefficients for estimating the adfreeze bond strength for pile design.



(a)Joomoonjin sand



(b)Weathered granite soil

Figure 6. Coefficient r_s of two test materials for predicting adfreeze bond strength

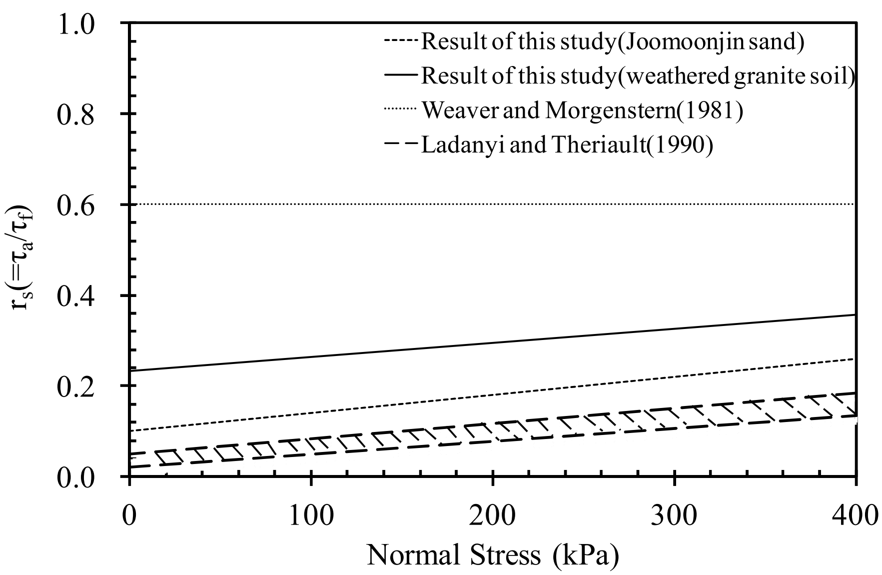


Figure 7. Coefficient r_s from this study and previous studies at -2℃

4. CONCLUSION

To identify the shear strength and adfreeze bond strength characteristics for foundation design in cold regions, many researchers have developed test techniques and carried out analyses of shear strength, adfreeze bond strength, and the relationship between the two strengths. However, the many studies of these two strength characteristics of frozen soils carried out over the last fifty years have been limited, as the strength characteristics of frozen soils can be affected by various influencing factors such as intrinsic material properties, pile surface roughness, and externally imposed testing conditions. In this study, direct shear testing inside of a large-scale freezing chamber was conducted in order to analyze the shear strength and adfreeze bond strength characteristics with varying freezing temperatures and normal stress with two soil types, and the relationship between the adfreeze bond strength and shear strength of frozen soils was analyzed.

While we do not yet have definite answers to all questions raised in this paper, several conclusions can be reached with a high level of confidence. An accurate description of strength characteristics is a prerequisite for foundation design in cold regions. The test equipment described in this paper provides a promising approach to solving some of these problems, and facilitates the evaluation of strength characteristics of frozen soils. Also, according to our test results the previous proportional coefficients describing the relationship between shear strength and adfreeze bond strength are unreliable predictors of true adfreeze bond strength characteristics in all conditions. For pile design in frozen ground, it is recommended to compare the design parameters from several research results and obtain the most suitable one for the field conditions.

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