Field Operation of an Artificial Perched Watertable Machine*

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Abstract

To retain summer runoff rain-water, an artificial perched watertable was constructed at about 0.5 m depth in an area where the annual precipitation occurs mostly in the summer season. The water in the sand-filled permeable layer could be used as capillary water for plants in the dry season. A special machine was developed to create the artificial perched watertable. This paper deals with the field operation testing of this machine.

The results showed that when the soil water content was more than the plastic limit (PL) and the soil penetration resistance of the field was less than 2 MPa, the penetrating velocity of the injector into ground was constant at about 50 mm s⁻¹ and an insert of 0.5 m in depth was obtained. A perfect underground cavity was produced due to the horizontal rupture fracture of the soil, when the soil water content was more than 25% d.b. Hence, when this machine is operated in a field, in order to obtain the perfect insert of the injector and the perfect underground cavity production, the soil water content should be more than the plastic limit. Charging air into the charge tank and charging sand into the sand tank occupied 98% of the total time. Charging air into the charge tank required 93% of the total operating energy.

[Keywords] dry areas, underground, water storage, soil hardness, underground cavity

I  Introduction

The annual precipitation in the Three-river Plain of the Black Dragon Province of People's Republic of China is only 600-700 mm. Moreover, the monthly rainfall is uneven; that is, about 60-70% of the annual precipitation occurs in July and August, and there is almost no rainfall in the winter and spring seasons. Plants often suffer due to excessive moisture during the growing season in the summer, and alternately, to drought during the seeding season in the spring. If heavy rain occurs in the summer season, the runoff flows on the soil surface and gathers at the lowest place in the field because soils in this area are planosol (Araya et al., 1996) and meadow soil (Zhang & Araya, 2001), both of which are quite impermeable. The lowest place becomes a pond during every rainfall, and the plants there are submerged at that time.

The annual precipitation in the North of River and Inner Mongolia Provinces is much less, only 300-400 mm. Here, too, the monthly rainfall is uneven; about 70% of the annual precipitation occurs once with hail in July and August. Soil in this area is whitish oasis soil (Guo & Araya, 2002), which is also quite impermeable. Hence, almost all rain water cannot penetrate into the soil and becomes runoff loss on the soil surface, eventually flowing into the rivers. As a result, there is water in the rivers only in the rainy season of July and August in this area.

By constructing an artificial perched watertable at about 0.5 m depth from the soil surface as described in the previous papers (Araya & Guo, 2002a; 2002b), it was intended to retain the summer runoff preferentially in this watertable, thus preventing excess moisture loss. The water in the artificially formed permeable layer could be available for crops and grasses as capillary water in the dry spring season in the Black Dragon, North of River and Inner Mongolia provinces. To accomplish this, a machine to construct the artificial perched watertable was designed and built, as shown in Fig. 1 (Guo et al., 2004a). In current paper, this machine was operated in a field, and the maximum limit of the soil penetration resistance where the injector could penetrate into the ground without the lifting of the tractor on the soil surface.

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was determined. Moreover, the size of the soil cavity produced underground (i.e., the size of the artificial underground watertable) was determined with different soil water contents. These parameters are useful for the efficient field operation.

II Prototypical Machine for Constructing an Artificial Perched Watertable

Figure 2 shows a schematic diagram of the machine in Fig. 1. It is attached to a tractor by a three-point linkage. When the hydraulic hoist (Fig. 1) is operated, the injector penetrates to a depth of 0.4-0.6 m where there is a B horizon in the planosol field (Araya et al., 1996), Cg1 horizon in the meadow soil (Zhang & Araya, 2001) and C horizon in the whitish oasis soil (Guo & Araya, 2002) which are all impermeable.

Next, with the air valve (Fig. 2) closed, the air compressor pressurises the charge tank. When the air valve is opened quickly, the high pressure air (1 MPa) is injected into the soil from the nozzle at the tip of the injector. If the soil has poor air permeability (air permeability $k_a \leq 0.2$ s), as described in the previous paper (Araya & Guo, 2002a), a large, horizontal and cylindrical cavity (crack) is then produced by the static air pressure (Fig. 2). The sand valve on the sand tank is closed at this time. When a suitable air cavity is obtained, the air valve is closed, and the charge tank is pressurised again. Next, the sand valve on the sand tank is open, and sand is charged in the injector. When the sand valve is closed and the air valve is opened again, the sand in the injector is forced explosively from the nozzle by the high pressure air to fill the cavity.

The injector has nozzles pointing in four directions. The sand would be injected initially from a nozzle with the least resistance. When the sand is filled in this direction and the flow resistance of this nozzle increases, the sand would be injected from another nozzle. Thus, the nozzles would operate one by one. When the cavity is completely filled in all directions, the hydraulic hoist is operated slowly to raise the machine onto the soil surface while still injecting sand. In this way, the horizontal soil cavity and the vertical hole can be filled with sand. The excess runoff occurring in the summer season could be held in the underground vertical and horizontal sand-filled spaces.

The water in the perched watertable can not percolate into lower layer because of the impermeability, but it could be transported by capillary action to the topsoil because the topsoil is tilled (Fig. 2).

III Experimental Details

1. Penetration of injector

The soil hardness where the injector could penetrate into ground was determined. A field test was held in Japan
where the field soil was pseudogley soil (Zhang & Araya, 2001). Its soil particle distribution was similar to that of the whitish oasis soil in China (Guo et al., 2004b), and so, the subsoil was quite impermeable. When rainfall occurred on the test field, and then the soil water content stabilized, the field operation was carried out.

The watertable construction-machine (Fig. 1) was attached to the three-point linkage of a tracked vehicle (Yanmar CT551, 3170 kg and 40.5 kW). When the injector (100 mm×100 mm) was inserted into the soil (Fig. 3), 2.4 kN of the weight of this construction machine and about 20 kN of rear wheel weight of the tractor worked on the tip of the injector.

Under these conditions, the injector was inserted into the soil with different soil penetration resistances. The engine speed was set at 1200 rpm, and the velocity of penetration of the injector was measured by a stopwatch. The soil penetration resistance was determined by a cone penetrometer (30° cone angle and 16 mm base diameter).

2. Size of the produced cavity

When the injector penetrated to a depth of 0.5 m, and the high pressure air (1 MPa) in the charge tank was injected into the soil, the size of the cavity produced at this time was determined as follows. When the cavity was produced underground, the soil surface upheaved, and this height was measured by a scale attached to the injector. At the moment of soil surface upheaval, ten pegs were set at the soil surface, and the distances between each peg and the centre of the injector were measured. The average distance was the cavity radius. We assumed that the shape of the cavity was cylindrical (Fig. 2) and calculated the volume accordingly.

3. Operation time of watertable construction machine

When the machine was operated at the field, time was measured with a stopwatch for charging air into the charge tank, penetrating the injector into the ground, producing the cavity, charging sand into the injector, filling sand into the cavity and pulling out the injector onto the soil surface.

4. Required energy

The required energy of these operations was calculated as follows. The energy of charging air into the charge tank is a product of the pressure in the charge tank (1 MPa) and the volume of the charge tank. The energy of penetrating the injector into underground is a product of the force working on the injector and the inserted depth of the injector. The energy of charging sand into the sand tank is a product of the weight of the charged sand and the height of the sand tank.

5. Soil water content and air permeability

The soil water content was measured by a commercial infrared moisture meter with a 5 g soil sample.

The air permeability of soils was measured by an apparatus which provided air flow into the soil cell under pressure (Araya & Guo, 2002a).

IV Results and Discussion

1. Penetration of injector

Figure 3 shows the injector penetrating into the ground. Figure 4 shows the measured velocity of this penetrating injector in mm s⁻¹. When the soil was wet and the soil penetration resistance of the field was less than 2 MPa, the velocity of the penetrating injector was constant at about 50 mm s⁻¹ and a perfect insert was obtained. When the soil penetration resistance was 2-3 MPa, the penetration of the injector became unsteady and the penetrating velocity was not constant. At resistance greater than 3 MPa, the injector could not penetrate into the ground.

The soil penetration resistance at a whitish oasis soil field...
in China just after rainfall was less than 1.5 MPa up to 600 mm (subsoil) in depth (Kuang et al., 2006). Therefore, if the field operation is performed just after rainfall, this injector penetration system will be adequate.

2. Size of the produced cavity

Figure 5 shows the state of the soil surface after operation by this machine. Soil clods of about 100 mm in diameter were produced (mixed with the injected sand) and scattered in a circle of about 1 m in diameter on the soil surface.

Figure 6 shows the underground conditions after operating the machine. It clearly produced a horizontal sand chamber about 3 m in diameter and about 0.2 m in thickness, as well as a vertical sand column at the centre. The runoff produced in summer season will be retained in these spaces.

Figure 7 shows the volume $V_c$ in m$^3$ of the cavity produced underground as a function of the soil water content. When the soil water content $\theta$ of the pseudogley soil was more than 25% d.b., a perfect cavity such as Fig. 6 ($V_c \approx 1.4$ m$^3$) was produced. When the soil water content was less than 25% d.b., the volume of the produced cavity decreased sharply because air permeability $k_a$ in the soil became $\geq 0.1$ s and air could easily flow among soil particles.

Figure 8 shows the aspect of the soil failure which was changed due to the value of the air permeability $k_a$. When the soil water content was less than 25% d.b. and $k_a$ ranged from 10 to 0.1 s, the V-shaped soil failure (small failure volume) took place (Fig. 7) and when the soil water content became more than 25% d.b. and $k_a$ was less than 0.1 s, the soil cavity production (large failure volume with rupture fracture) took place (Fig. 7). The value of $k_a$ of 0.1 s is a boundary value (criterion, Araya & Guo, 2002a).

The plastic limit (PL) and liquid limit (LL) of the pseudogley soil were determined to be 23.7% d.b. and 34.6% d.b., respectively (Fig. 8). Hence, in order to obtain the perfect insert of the injector and the perfect cavity production (the horizontal rupture fracture of the soil), the soil water content should be more than about the plastic limit.
3. Operation time of watertable construction machine

Table 1 shows the average measured operation times of the machine. The volume of the sand accumulator (Fig. 1) of the injector was about 0.35 m³, so making one cavity required roughly four times this volume of sand and five cycles of charging air. Total required time for one cavity production was 0.74 h (45 min). Charging air into the charge tank and charging sand into the sand tank occupied 98% of the total time. In order to decrease this total operation time, the compressor should be stronger and the size of the sand accumulator should be larger.

Table 1 also shows the required energy for each operation. The energy for charging air into the charge tank was 93% of the total required energy, and that for charging sand into the sand tank was 7%.

V Summary and Conclusions

This paper deals with the problem of water retention by soil in three Chinese provinces: Black Dragon (Three-river Plain), North of River and Inner Mongolia. We designed and built a machine to create an artificial perched watertable. In this paper, the machine was tested in actual field conditions similar to those in China.

1. The best insertion of the injector was obtained when the soil was wet and the soil penetration resistance of the field was less than 2 MPa. When the soil penetration resistance was 2-3 MPa, the penetration of the injector became unsteady and the penetrating velocity was not constant. Above 3 MPa resistance, the injector could not penetrate at all.

2. When the soil water content was more than 25% d.b., an ideal cylindrical cavity was obtained. With the soil water content less than 25% d.b., the volume of the produced cavity decreased.

3. Hence, in order to obtain the perfect insert of the injector and the perfect cavity production, the soil water content should be more than about the plastic limit.

4. Charging air into the charge tank and charging sand into the sand tank occupied 98% of the total operating time.

5. Charging air into the charge tank required 93% of the total operating energy.

References


Table 1 Average operation times and required energy of machine for artificial perched watertable

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time, h</th>
<th>Energy, J</th>
</tr>
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<tbody>
<tr>
<td>Charging air into charge tank</td>
<td>0.640 (421 s x 5 times)</td>
<td>1.1 x 10⁶</td>
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<tr>
<td>Penetrating injector into underground</td>
<td>4.72 x 10⁶ (74 s)</td>
<td>5.0 x 10⁹</td>
</tr>
<tr>
<td>Producing cavity</td>
<td>5.55 x 10⁶ (3 s)</td>
<td>-</td>
</tr>
<tr>
<td>Charging sand into sand tank</td>
<td>0.131 (11 s x 4 times)</td>
<td>8.3 x 10⁶</td>
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<tr>
<td>Filling sand into cavity</td>
<td>2.22 x 10⁶ (2 s x 4 times)</td>
<td>-</td>
</tr>
<tr>
<td>Pulling out injector onto soil surface</td>
<td>3.33 x 10⁶ (12 s)</td>
<td>1.0 x 10⁹</td>
</tr>
<tr>
<td>Total</td>
<td>0.793</td>
<td>1.2 x 10⁹</td>
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