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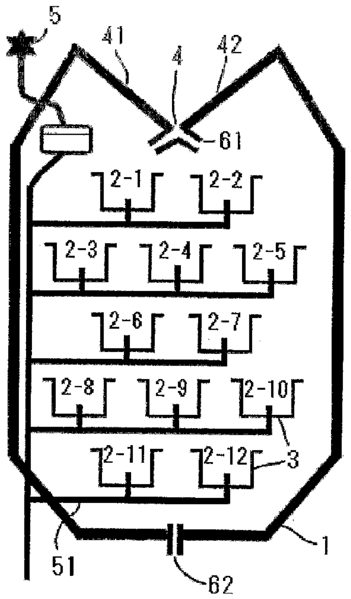
(54) Title: METHOD OF LAND REFORM FOR DRY LAND FORESTATION

(54) 発明の名称: 乾燥地植林のための土地改良方法



(57) Abstract: Hardpan is crushed with the use of detonating powder to thereby form holes of 50 cm or greater depth having 50 or more cracks of 0.5 mm or greater width in the lateral direction. Thus, scanty rainfall in dry land or semiarid land can be utilized with the maximum effectiveness, and soil thereof can be reformed so as to be suitable for forestation.

(57) 要約: 爆薬を用いてハードパンを破砕し、深さ50cm以上で、横方向に幅0.5mm以上のクラックを50本以上有する穴を形成することにより、乾燥地や半乾燥地における乏しい降雨を最大限に有効に利用し、土壌を植林に適したものへと改良する。

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Description

METHOD OF LAND IMPROVEMENT FOR AFFORESTATION OF ARID LAND

Technical Field

The invention of this application relates to a method of land improvement for afforestation of arid land. More particularly, the invention of this application relates to a method of land improvement in which hardpan in arid land is crushed and the soil suitable for afforestation is formed.

Background Art

In recent years, global warming is becoming a serious problem. Warming of temperature on a global scale causes worries of a rise in the sea level due to increase in sea water and melting of glaciers, frequent occurrence of abnormal weather due to changes in climate mechanisms, etc. and the effects on ecosystems, our living environment, agriculture, etc. cause concern.

The cause for the global warming is accumulation of the so-called greenhouse gases due to the use of fossil fuel and, with regard to suppression of the discharged amount thereof, various attempts are now conducted in an international scale. However, in actuality, the discharged amount of carbon dioxide is still increasing.

As a result of the development of civilization, many forests have been cut down for expansion of agricultural land, housing land and transportation means, or for utilization of wood. Since plants absorb carbon dioxide, produce carbohydrates, an energy source, by photosynthesis, and discharge oxygen, it has been proposed as a measure for global warming to positively utilize the absorption and fixation of carbon dioxide by forests. Thus, together with suppression of cutting down of forests, afforestation of arid land and semi-arid land occupying 1/4 to 1/3 of land on the earth is being attempted.

However, in many arid areas and semi-arid areas, there are many water-impermeable layers (hardpan) (Pate, J. S., W. H. Verboom and P. D. Galloway, *Australian Journal of Botany*, 49, 529-560 (2001)) and, therefore, water provided by rainfall does not permeate into the earth but is evaporated from the soil surface and there is the problem that amount of the utilizable water is extremely small. It has been also reported that hardpan is a layer formed by hydration and hardening of silica, iron, calcium, etc. (Bettenay, E. and H. M. Churchward, *J. of the Geological Society of Australia*, 21, Pt. 1, 73-80 (1974)) and is hard whereby there is a problem that, even if afforestation is carried out, roots of seedlings are unable to break through it and spreading of roots widely into the earth is not possible. Therefore, the actual state is that afforestation in an arid area is poor and the effect of absorption and fixation of carbon dioxide on a large scale is not feasible.

Now, the invention of this application has been achieved to deal with the aforementioned circumstances, and its object is to provide a method for improving the soil so that it is suitable for afforestation through the most effective utilization of rainfall, which is poor in arid and semi-arid regions.

Disclosure of the Invention

Accordingly, as a means for solving the aforementioned problem, the invention of this application provides a method of land improvement for afforestation of arid land, characterized in that hardpan is crushed using an explosive to form a hole with depth of 50 cm or more and having 50 or more cracks in the transverse direction with width of 0.5 mm or more there at.

Brief Description of the Invention

Fig. 1 is a bird's-eye view of the area (site C) where land improvement and afforestation are carried out in the Examples of the invention of this application.

Fig. 2 is an approximate schematic depiction showing the constitution of the area (site C) where land improvement and afforestation are carried out in the Examples of the invention of this application.

Fig. 3 is a drawing which shows the amount of rainfall and the amount of water for irrigation at the area (site C) where land improvement and afforestation are carried out in the Examples of the invention of this application.

Fig. 4 is a drawing which shows degree of growth for each species of trees afforested at the area (site C) where land improvement and afforestation are carried out in the Examples of the invention of this application.

Fig. 5 is a picture which shows the state of roots of *E. camaldulensis* after one year from the planting of the seedling in the Examples of the invention of this application.

Fig. 6 is a picture which shows the state of roots of *C. obesa* after two years from the planting of the seedling in the Examples of the invention of this application.

Meanings of the symbols in the drawings are as follows.

1	bank for water catchment
2	pond
2-1	the first pond
2-2	the second pond
2-3	the third pond
2-4	the fourth pond
2-5	the fifth pond
2-6	the sixth pond
2-7	the seventh pond
2-8	the eighth pond
2-9	the ninth pond
2-10	the tenth pond
2-11	the eleventh pond
2-12	the twelfth pond
3	pond bank
4	V-shaped area of the water catchment bank
41	flow path (flow) 1
42	flow path (flow) 2
5	well or irrigation means
61	inlet
62	outlet

Best Mode for Carrying Out the Invention

The inventors of this application have planted in arid lands and carried out various investigations for afforestation as follows.

<Published papers>

Ikuo Abe, Noritomi Kojima and Koichi Yamada: A Large-Scale Afforestation in Arid Areas as a Measure against Increases in Carbon Dioxide, *Sabaku Kenkyu*, 7-1, 77-81 (1997)

Masahiko Taniguchi, et al.: Possibility of Large Scale Afforestation in Arid Lands as a Measure against Increases in CO_2 Concentration, *J. Arid Land Studies*, 7-S, 241-244

K. Yamada, et al.; Carbon Sequestration in an Arid Environment near Leonora, Western Australia, *Journal of Arid Land Studies*, 9, 143-151 (1999)

H. Hamano, et al.; A Study on Possibility of Bauxite Utilization to Improve Soil Properties for Afforestation of Arid Land, *Journal of Arid Land Studies*, 10S, 81-84 (2000)

Hiroyuki Hamano, Kiyotaka Tahara, Noritomi Kojima and Koichi Yamada: In Situ Measurement of Saturated Hydraulic Conductivity in Arid Land and Analysis of Soil Layer Structure, *Nogyo Dobokugaku Rombunshu*, 216, 33-40 (2001)

Hiroyuki Hamano, Noritomi Kojima, Ikuo Abe and Koichi Yamada: Analysis of Water Transport in Soil of Arid Land and its Application to Large Scale Afforestation, Journal Arid Land Studies 12(3), 127-140 (2002)

<Presentations at the Meetings>

Masahiko Taniguchi, Ikuo Abe, Noritomi Kojima, Hiroyuki Hamano, Koichi Yamada and John Law: Afforestation and Soil Search in Arid Lands in the Western Australian States, Japan Desert Science Society (1998)

Koichi Yamada: Carbon Fixation by Afforestation of Arid Lands, The 65th Annual Meeting of the Japanese Chemical Engineering Society, Tokyo, March 29 (2000)

Project Team "Construction of Carbon Fixation System by Afforestation in Arid Lands" for Strategic Fundamental Study: Construction of Carbon Fixation System by Afforestation in Arid Lands, The 65th Annual Meeting of the Japanese Chemical Engineering Society, Tokyo, March 29 (2000)

Kiyotaka Tahara, Noritomi Kojima, John Law, Ikuo Abe, Nobuhide Takahashi and Koichi Yamada: CO_2 Balance of Afforested Arid Lands in Western Australia, The 33rd Fall Meeting of The Japanese Chemical Engineering Society, Hamamatsu, September 14 (2000)

Project Team "Construction of Carbon Fixation System by Afforestation in Arid Lands" for Strategic Fundamental Study: Construction of Carbon Fixation System by Afforestation in Arid Lands in Western Australia, The Fall Meeting of the Japanese Chemical Engineering Society in 2001

Nobuhide Takahashi, Kiyotaka Tahara, Masahiro Saito, Ikuo Abe, Noritomi Kojima and Koichi Yamada: Growth of Trees after Afforestation in Arid Lands and Soil Improvement Effect, The 67th Annual Meeting of the Japan Chemical Engineering Society (2002)

Kiyotaka Tahara, Nobuhide Takahashi, Gen Utogi, Toshiko Tanaka, Noritomi Kojima and Koichi Yamada: Estimation of Water Utilization Efficiency of Trees in Arid Lands in Western Australia, The 13th Scientific Meeting of the Japan Desert Science Society, June 1 to 2, Tsukuba (2002)

Koichi Yamada, Noritomi Kojima, Ikuo Abe, Masahiro Saito, Yasuyuki Eto and Nobuhide Takahashi: Carbon Fixation by Afforestation in Arid Lands of Australia, Tottori Meeting of the Japan Chemical Engineering Society, July 25 to 26, Tottori (2002)

Hiroyuki Hamano, Nobuhide Takahashi, Masahiro Saito, YasuyukiEto, Ikuo Abe, Noritomi Kojima and Koichi Yamada: Optimization of Bank Creation for Control of Surface Effluence in Afforestation in Arid Lands, The 35th Fall Meeting of the Japanese Chemical Engineering Society, September 18 to 20, Kobe (2002)

A method for land improvement according to the invention of this application has been found through these investigations and can be said to be the first important step for afforestation of arid lands. Thus, as mentioned already, its object is to utilize sparse rainfall to a maximum extent and to make an arid land suitable for afforestation. Incidentally, in the present specification, "arid land" means an arid land which has become a desert or semi-arid land where annual rainfall is less than 300 mm.

The first problem in afforestation in an arid land is the so-called hardpan which is a shallow water-impermeable top layer of the earth (J. S. Pate, W. H. Verboom and P. D. Galloway, *Australian Journal of Botany*, 49, 529-560 (2001)). Hardpan is a shallow top layer of the earth, in other words, near the surface of the earth, and is a hard layer formed by hydration hardening of silicon, iron, calcium compounds, etc. (E. Bettenay, and H. M. Churchward, *J. of the Geological Society of Australia*, 21, Pt 1, 73-80 (1974)) and, therefore, it is difficult to dig a hole for planting the seedling. In addition, even when a suitable hole can be formed using a farming tool, etc., the seedlings planted there cannot form roots and no growth is possible.

Now, in a method of land improvement for afforestation of arid land according to the invention of this application, the hardpan is first crushed by blasting. As a result of the blasting of hardpan, a hole for implanting the seedlings is formed, and at the same time, many cracks or fissures are made in the hardpan. Such cracks are not only important water-permeating paths for permeation of water into deep area of the earth upon rainfall but also the so-called opening opportunities for the growth of roots of seedlings in a horizontally in the hardpan and vertically to lower layers. Accordingly, they promote sufficient growth of the roots for the trees to grow to a big size.

Moreover, since hardpan has a layer structure which is easily cracked, many cracks are formed in a horizontal direction by blasting of hardpan. In a rainy season, water is stored in the cracks and is a source of water for the roots of the trees extending into the cracks. In addition, the drying speed of water stored in the cracks is suppressed by the water-impermeable hardpan layers below and above the cracks.

The hole formed in hardpan at that time is a size suitable for planting of seedlings and, in order to plant the seedlings of a sufficient size, it is desirable that it has a depth of 50 cm or more. It is also desirable that, in such a hole, 50 or more cracks with width of 0.5 mm or more are formed. Further, such cracks can be formed at intervals of, for example, 20 cm or less.

The inventors of the present application have made intensive studies on land improvement for afforestation of arid land with the following objectives:

(a) permeation of water into the soil during rainfall is promoted,

(b) evaporation of water from the soil is suppressed,

(c) water content of the soil is increased and

(d) acquisition of water by the tree and prevention of toppling of the tree through growth of roots are achieved.

As a result, they have found that these objectives can be achieved when a hole of diameter of 50 cm or more and 50 or more cracks each with a width of 0.5 mm or more at this hole are formed as mentioned already. The inventors of this application have also confirmed that, when diameter of the hole is less than 50 cm, even when the water content in the soil at the bottom of the hole reaches a saturated state after rainfall, when a dry season (period of no rainfall) continues for two to three months after that, water content in the soil decreases below the point where the tree droops and the tree is apt to be wither and die. It has been further confirmed that, when numbers of the cracks are less than 50, the absolute amount of water in the soil becomes small and, in addition, numbers of the roots extending into the cracks also become small and accordingly that amount of water supplied via roots during the dry season is insufficient so that the tree is apt to wither and die, and, due to insufficient strength supporting the tree, the tree is apt to be toppled by strong wind (15 m or more per second). Incidentally, the width of the crack is preferred to be small, but when cracks having width of less than 0.5 mm are formed, a lot of blasting energy is needed and, moreover, size of a root is usually 0.5 mm or more and, if the size is smaller than that, extension of the root into the crack does not take place, so that it is preferred that the width of a crack is 0.5 mm or more.

In a method of land improvement for afforestation of arid land according to the invention of this application, the type and amount of the explosive used for formation of the aforementioned hole can be appropriately varied depending upon size of the land to be treated, size of the aimed hole and depth, thickness, etc. of hardpan and are not particularly limited. For example, a hole of 7 cm diameter and 3 m depth is formed on hardpan of 6 m thickness using a drill, 10 kg of ammonium nitrate and 0.6 kg of light oil are placed therein, the hole is clogged by sand and stone and explosion is conducted whereupon a conic hole of 3 m diameter and 4 m depth is formed. The inventors of the present application have also confirmed that, in hardpans around the hole formed as such, more than 100 cracks having a space of 3 to 10 mm are formed in layers.

As mentioned hereinabove, a method of land improvement according to the invention of this application is characterized in that hardpan is blasted into pieces with cracks between them and, besides this direct cracking method, it is possible to use concomitantly a means such as cultivating, irrigation, mixing of water absorber, water retainer, etc. in the soil, or addition of fertilizer etc.

Especially in a land improvement for afforestation of arid land, it is important to ensure the supply of water, and it is preferred to consider utilization of groundwater and catchment of rainfall. It is also possible to apply a process where pure water is manufactured from seawater or lake water by a reverse osmotic method or an evaporation method. However, such a method discharges more CO_2 than is expected to be absorbed by afforestation and, therefore, that method is not preferred when absorption and fixation of CO_2 are objectives. Accordingly, it is desirable to install a water catchment device which is able to suppress the flowing out of water upon rainfall and to accumulate the water at the afforested area.

Hereafter, Examples will be shown so that the embodiments of this invention will be illustrated in more detail. It goes without saying however that this invention is not limited to the following Examples, and various modifications are possible with respect to particular points.

Examples

<Example 1>

(1) Method

(Object Area)

An area of 50 km × 50 km in Sturt Meadows, Leonora which is 600 km apart in the east-northeast direction from Perth, capital of the state of Western Australia, was used as the site for the test.

Although average annual rainfall in this area is 222 mm, it varies depending upon seasons and rainfall in summer time is very low.

Average slope of this area is less than 2% and one half of the rainfall flows into a salty lake of 50 km × 50 km located to the south of the above-mentioned area and is evaporated. Further, most of this area is covered by hardpan and, in the case of heavy rainfall (20 mm or more), water is apt to flow out and not be absorbed. Therefore, shallow hardpan in this area is uncovered or has only sparse grass, and afforestation is rarely noted while, in deep hardpan, only sparse woodland of *Acacia aneura* (acacia) is formed. Although some dense forests of *Eucalyptus camaldulensis* (eucalyptus) are present, they are limited to the area where surface layer is thick and abundant groundwater is available.

Particularly in the area (site C) which is about 10 km north of the Meteorological Observatory, there are only a few centimeters of surface soil on hardpan which is several meters thick, and hardly any plants are found. This site C was used as a test area for land improvement and afforestation.

(Preparation)

Fig. 1 shows a bird's-eye view of the site C and Fig. 2 shows an approximate schematic depiction showing the constitution of the site C. Around the water catchment area which has width of about 400 m and length of about 600 m, a water catchment bank (1) was constituted so as to surround the area and, in the water catchment area, 12 ponds (2) having afforesting zone of 50 m width and 40 m length were formed (2-1 to 2-12).

The pond banks (3) were formed using a bulldozer to a height of 1m. A part of the water from upstream was taken accumulated in a V-shaped part (4) of the water catchment bank and was made to flow into a reservoir area from an inlet (61) equipped with a flow rate meter.

A well (5) was drilled so that water could be supplied during the dry season.

Further, in order to measure the rainfall amount at the site C, an automatic recorder was installed.

Average irrigation per month was calculated as follows.

Monthly Amount of Irrigation Water = Numbers of trees × Average Water Supplied to Each Tree × Water Supplying Time

Furthermore, the monthly amount of irrigation water was divided by the area of the reservoir area to compare with monthly rainfall (unit: mm).

(Land Improvement and Afforestation)

Hardpan was crushed at each afforested area and downstream of the water-catchment area. Firstly, a hole of 7 cm diameter and 3 m depth was formed using a drill, 10 kg of ammonium nitrate and 0.6 kg of light oil were placed therein, the hole was clogged with soil and stone, and the hole was blasted. By this method, 49 holes each having diameter of 3 m and depth of 5 m were formed on a pond (2) of 50 m × 40 m. Incidentally, at the fifth pond (2-5) only no blasting was carried out and it was used as a control.

Seedlings of various kinds of trees including naturally grown ones were planted one each in the center of each hole and 4.6 kg of sheep manure was added to each hole as a fertilizer.

(2) Results

(State of Water Catchment)

After the pond bank (3) was constructed and trees were planted, there were several rainstorms where the amount of rainfall was 20 mm or more. Water flowing from the area to the northeast was effectively introduced into the V-shaped part (4) of the water-catchment bank, divided into two flows (41, 42) and distributed into 12 ponds (2-1 to 2-12). In the fifth pond (2-5) where no crushing of hardpan was carried out, the distributed water was not permeated into the soil and thus was stored thereon for a long period while, in other ponds (2-1 to 2-4 and 2-6 to 2-12), water was permeated into the deep layers of the soil.

The proportion of irrigation water amount to the corresponding monthly rainfall was calculated by the aforementioned formula and shown in Fig. 3 together with the actual rainfall data.

In the period of high temperature and low rainfall, the frequency of irrigation was increased, and irrigation was not conducted during periods of intense rainfall.

(Growth of Trees)

Every one half year, diameter at breast height (about 130 cm) of the person who conducted the measurement and width of the tree crown were measured to observe the growth of the tree. Average height of the trees of each species is shown in Fig. 4.

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Since no crushing of hardpan was conducted in the fifth pond (2-5), surface soil was thin and only small seedling less than 1 m in height could be planted. In the case of *Casuarina obesa* (beefwood), only seedlings of 1 m or more are available and, therefore, they could not be planted on the fifth pond (2-5).

Average biomass, average growing speed and average survival rate per unit area in all ponds (2-1 to 2-4 and 2-6 to 2-12) except the fifth pond (2-5) were shown in Table 3.

Dry mass of the tree was calculated by using the relation formula for dry mass and height obtained by investigation by means of cutting-down sampling of many species which are naturally growing in this searched area.

Average growing speed was determined by dividing the dry mass of the trees increasing in each pond during a certain period by the area (50 m x 40 m) of the pond.

Table 3

	Biomass (kg/cm^2)			Degree of Growth (kg/m^2/year)			Survival Rate (%)
	Immediately after Planting	After 10 Months	After 22 Months	Immediately after Planting	After 10 Months	After 22 Months	
All Ponds except Pond 5	0.17	0.35	0.82	0.22	0.47	0.36	87
Pond 5	0.005	0.04	0.21	0.05	0.16	0.11	52

Among the ponds (2-1 to 2-12), there was no big difference in the growing speed of the tree. On the other hand, in the fifth pond (2-5), only a low value was achieved in tree height, biomass and growing speed. The reason therefor is that only seedlings less than 1m in height could be planted. The fact that growth of the roots was not possible also was a factor.

In terms of the species of the trees, growth of *C. obesa* and *E. camaldulensis* was particularly quick. On the contrary, growing speed of *A. aneura* was lower than the above two species and was in the same degree as others belonging to genus *Eucalyptus*. With regard to the growing speed of trees of *A. aneura*, there is no big difference between the fifth pond (2-5) and other ponds (2-1 to 4 and 2-6 to 12). The cause for such a result is that *A. aneura* extends its root in a horizontal direction in a shallow surface layer soil.

(Extension of Root)

Soil and hardpan lumps at one side of each tree were crushed and removed with water pressure so as not to cut the root. A picture of the state of the exposed root was taken, diameter was measured, total volume was estimated, and the relation between the diameter at the base of the root and the total volume of the root was calculated. Incidentally, after the investigation, the root was covered with the soil again and water was given thereto.

Extension of the root of *E. camaldulensis* one year after planting is shown in Fig. 5. Many roots extend downward 2.5 m (maximum depth of the holes made for this investigation) or deeper and extend into the gaps formed by crushing of hardpan, and also there were also some roots extending horizontally. In addition, a part of the roots extended even into narrow cracks.

Further, two years after planting, extension of the root was measured and it was found that the root was thicker than that shown in Fig. 5 and the extension of roots was to such an extent that the deepest position of the root could not be confirmed. As a result, it can be expected that when the tree grows, its roots extend and are able to suck up the groundwater.

The state of the root of *C. obesa* two years after planting is shown in Fig. 6. As compared with *E. camaldulensis*, there were many slender roots, and the direction of the root extension was more broadly and uniformly distributed. Those roots came into even small cracks formed by crushing of hardpan, extending 2 m or more in some cases. As a result, it has been shown that extension of the roots in horizontal and vertical direction is promoted by the cracks formed by crushing.

Accordingly, in the improvement of arid land for afforestation, importance of formation of cracks in hardpan together with supply of water to the soil has here been shown.

<Example 2>

(1) Method

In the afforesting area of Example 1, a hole whose diameter was 70 cm and depth was 60 cm, together with 80 cracks of width 1 mm or more at this hole, were formed by the same method as in Example 1 and seedlings of *E. camaldulensis* (height of about 40 cm) were planted.

(2) Results

The growth of the seedlings after two years was confirmed to be as much as 2.5 m.

<Comparative Example 1>

(1) Method

A hole whose diameter was 30 cm and depth was 30 cm, and 30 cracks of width 1 mm or more at the hole were formed by the same method as in Example 2 and seedlings of *E. camaldulensis* (height of about 40 cm) were planted in the same manner.

(2) Results

The seedlings withered and died after one year.

<Example 3> Evaluation of life cycle of carbon dioxide

Life cycle of CO_2 discharged from the method of land improvement of the present invention and from the process of afforrestation was evaluated.

The amount of CO_2 which was directly discharged as a result of the same material, equipment and combustion as those used in Example 1 was calculated by means of an NIRE-LCA software (ver. 2) (Tahara, K., T. Kojima and A. Inaba, *Energy Conversion and Management*, 38, 615-620 (1997)). Incidentally, the unit for discharge of CO_2 is that which has been adopted in Japan. Direct discharge of CO_2 by explosion of dynamite was disregarded.

The total amount of CO_2 discharged by crushing of hardpan required for planting of 700 seedlings was calculated as 9.6 t of CO_2 or 2.6 t of carbon. Even when other energy necessary for construction of banks and fences is added thereto, discharged amount is 33 t of CO_2 or 9 t of carbon and that corresponds to 13 kg of carbon per tree. However, when one tree grows, 500 kg of carbon is estimated to be fixed and therefore, the amount of CO_2 discharged by the method of the present invention is negligible compared with the amount of CO_2 which can be absorbed and fixed.

Industrial Applicability

As fully illustrated hereinabove, this invention is able to provide a method for land improvement whereby afforestation of arid land is made possible.

In the method of this invention, hardpan is crushed by blasting, whereby extension of root and growth of tree are dramatically accelerated. In addition, the amount of CO_2 discharged by the method of this invention is only 1/40 of the CO_2 which is able to be absorbed upon growth of the planted trees, so that the usefulness of this method for dealing with the problem of the global warming is high.

Claim

1. A method of land improvement for afforestation of arid land, characterized in that hardpan is crushed using an explosive to form a hole with depth of 50 cm or more and having 50 or more cracks in the transverse direction with width of 0.5 mm or more there at.

Fig. 1

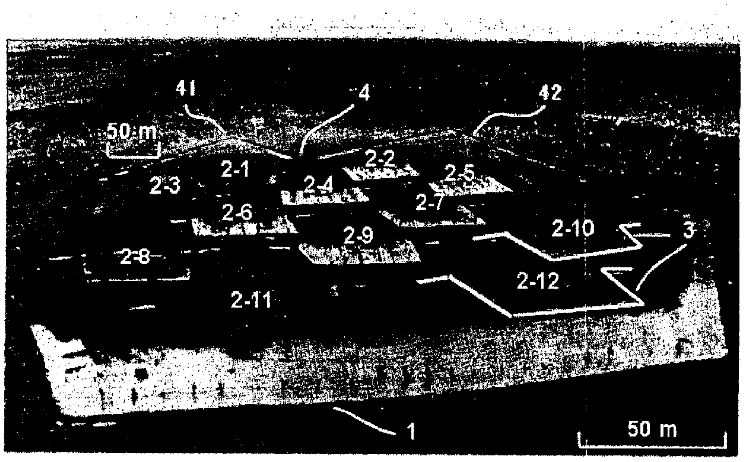

Fig. 2

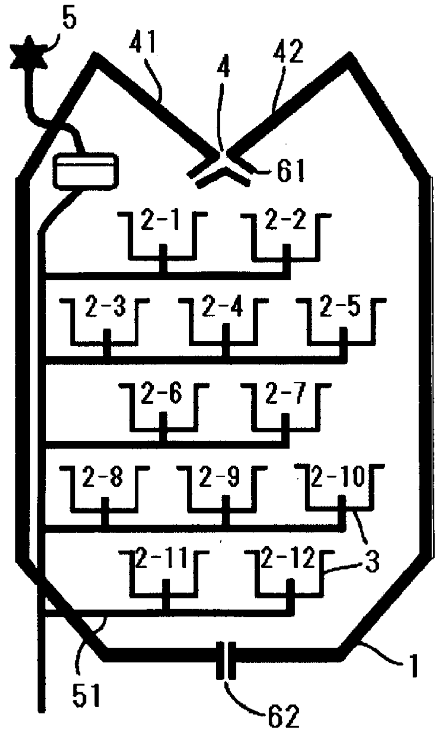

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Fig. 3

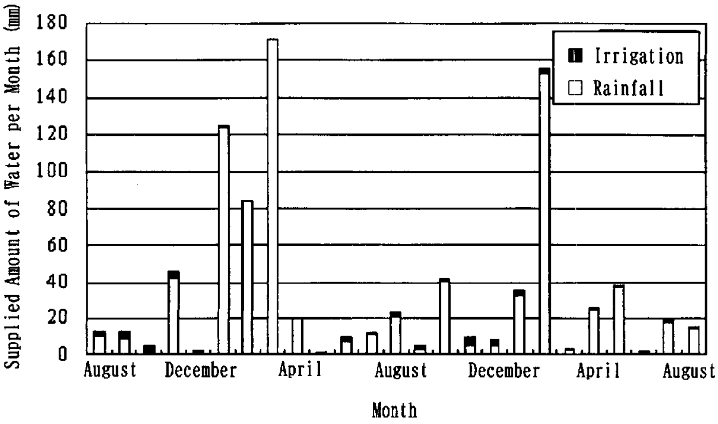
Supplied Amount of Water per Month (mm)
180
160
140
120
100
80
60
40
20
0
Irrigation
Rainfall
August
December
April
August
December
April
August
Month

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Fig. 4

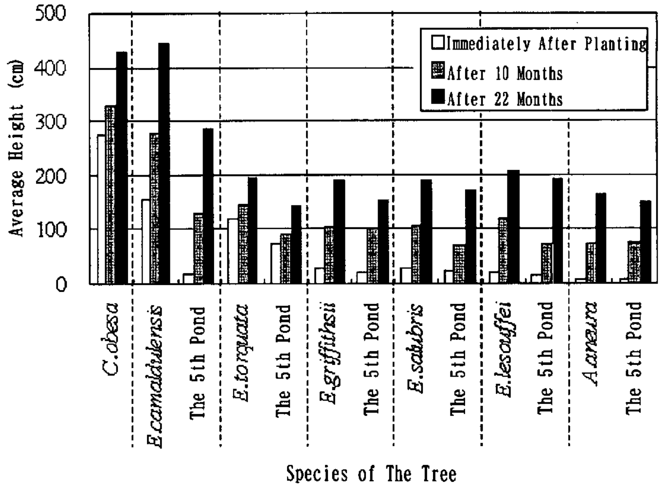
500
400
300
200
100
0
Average Height (cm)
Immediately After Planting
After 10 Months
After 22 Months
C.obesa
E.camaldulensis
The 5th Pond
E.torquata
The 5th Pond
E.griffithsii
The 5th Pond
E.salubris
The 5th Pond
E.lesouffei
The 5th Pond
A.aneura
The 5th Pond
Species of The Tree

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Fig. 5

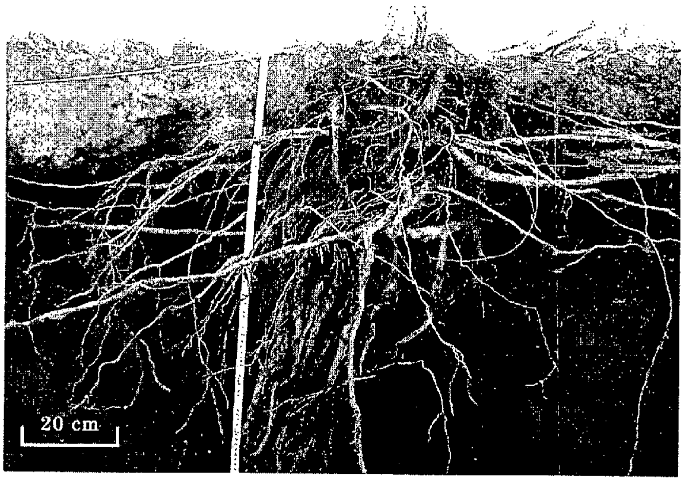

Fig. 6