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Application of 17 Wild Plant Species in Afforestation of an Abandoned Quarry

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ABSTRACT

In order to rapidly restore the vegetation of an abandoned quarry and improve its ecological and landscape effects, 17 wild plant species with drought and barren soil-tolerance were selected and planted in an abandoned quarry in Shenzhen, Guangdong province in south China, termed the "Fuyuan" quarry. The adaptability of these species to the adverse conditions and their effects on ecological restoration and landscape improvement were studied. Ultimately, only species suitable for afforesting the abandoned quarry were selected. The species introduced were maintained for first one year and then left alone to grow naturally. The increases in plant height and crown diameter of these species were measured at the end of the first year after planting, and their survival percentage and coverage were evaluated after three years. Results showed that *Cudrania cochinchinensis* (Lour.) Kudo *et* Masam., *Lagerstroemia kweilinensis*, *Cudrania tricuspidata* (Carr.) Bur., *Delavaya toxocarpa* Franch., *Ficus gibbosa* Bl., *Cipadessa cinerascens* (Pell) H.M., *Randia spinosa*, *Pueraria lobata* var. montana (Lour.) Merr. and *Bauhinia corymbosa* Roxb. could be applied in the afforestation of the steep and large-scale barren cliff, while *Indigofera enneaphylla* L. and *Ficus tikoua* Bureau. were suitable for greening the slashed land.

Keywords: adaptability, growth increment, selection, survival rate
Abbreviations: DMRT, Duncan's new multiple's range test; **EW × NS**, the distance from east to west multiplied by the distance from north to south

INTRODUCTION

Quarries bring harm and problems to the environment, ecosystems and landscape (Fang *et al*. 2004). Reforestation of abandoned quarries – especially stiff slopes – has been a difficult issue worldwide and increasingly attention is being paid to this issue. Various restoration techniques and administrative measures have been studied and set up in the last decades (Bradshaw 1983; Fang *et al*. 2004; Yang *et al*. 2005). Plant protection is the key technique. As plants grow, their intensity of protection increases, as does the need to stabilize slopes and reduce soil erosion at a low cost (Pan *et al*. 2005). Mechanical and hydrological studies (Fang *et al*. 2004) indicated that plant vegetation had good effects in stabilization of marginal shallow soils and in surface erosion control. The deep roots grew into mantle rocks and anchored into them. Plant cover can withstand heavy rain, maintain water and reduce soil splash and therefore reduce erosion, which generally decreases exponentially as plant cover increases (Zhang *et al*. 2002).

Many quarries have been abandoned and are waiting for reforestation during the rapid development in south China in the past decades. In the past, only simple plant species had been tried and only short-term effects were taken into account in many quarries. This study was aimed at plant selection from many indigenous species. The selection criteria were: a) a strong root system, b) fast growth, and c) high stress tolerance to drought and barren soil. To restore ecological environments, plant vegetation with diversified multifunctional species and increased levels in the configuration of multiplayer plants were our main considerations. Seventeen indigenous wild plant species fitted the selection criteria and were selected from 47 species according to their biological characters, growth trials and drought-tolerance. So they were applied in "Fuyuan" quarry's afforestation.

MATERIALS AND METHODS

"Fuyuan" quarry site and climate

"Fuyuan" quarry is a hill slope with weathered rock and semi-decayed rock. The slashed land's pH is 4.5-5.5.

Shenzhen belongs to a subtropical zone whose marine climate was temperate and subhumid (**Table 1**). The monthly average air temperature ranges from 14.5°C (January) to 28.4°C (July). The monthly average relative humidity ranges from 59% (December) to 80% (June). The monthly average precipitation is from 24.9 mm (December) to 351.5 mm (August). The monthly average radiation is from 298.8 MJ/m^2 (February) to 569.0 MJ/m^2 (July).

Plant species tested

Seventeen plant species were used in the experiments (**Table 2**).

Table 1 The climate at Shenzhen (quarry site).

Month	1	2	3	4	5	6	7	8	9	10	11	12
Air temperature (°C)	14.5	15.2	18.4	22.3	25.8	27.5	28.4	28.0	27.0	24.2	20.2	16.2
Relative humidity (%)	69	72	77	79	78	80	78	77	73	69	68	59
Precipitation (mm)	26.3	50.5	64.5	144.3	240.9	319.3	329.3	351.5	248.0	89.3	36.0	24.9
Radiation (MJ/m^2)	344.8	298.8	351.8	398.8	488.7	479.2	569.0	520.8	504.7	493.0	404.2	371.3

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Table 2 Plant species used.

Plant name	Family	Style	Characters
Cudrania tricuspidata (Carr.) Bur.	Moraceae	Arbor	Root system strong, bear drought
Delavaya toxocarpa Franch.	Sapindaceae	Arbor	Bear barren soil
Ficus gibbosa Bl.	Moraceae	Arbor	Distributed on stone hill
Cyclobalanopsis glauca (Thunb.) Oerst.	Fagaceae	Arbor	Bear barren soil
Flemingia latifolia Beth.	Leguminosae	Shrub	Bear barren soil
Pyracantha atalantioides (Hance) Stapf	Rosaceae	Shrub	Bear barren soil
Cudrania cochinchinensis (Lour.) Kudo *et* Masam	Moraceae	Shrub	Root system strong
Cipadessa cinerascens (Pell) H.M.	Meliaceae	Shrub	Distributed on stone hill
Lagerstroemia kweilinensis	Lythraceae	Shrub	Bear barren soil
Randia spinosa	Rubiaceae	Shrub	Distributed on stone hill
Indigofera enneaphylla L.	Papilionacea	Climbing bush	Grow fast
Pereskia aculeate Mill.	Cactaceae	Climbing bush	Bear drought
Jasminum elongatum (Bergius) Willd.	Oleaceae	Climbing bush	Distributed on stone hill
Berchemia lineata (Linn.) DC.	Rhamnaceae	Climbing bush	Bear barren soil
Ficus tikoua Bureau	Moraceae	Climbing bush	Bear drought and barren soil
Pueraria montana (Lour.) Merr.	Papilionacea	Vine	Grow fast
Bauhinia corymbosa Roxb.	Caesalpiniaceae	Vine	Grow fast

Planting and investigations

Planting canals on the rock walls were cut about 40 cm deep, 40-60 cm wide and refilled with improved soils (natural soil: peat: chicken manure = 10:2:0.5, pH 5.5-6.0) at two thirds of their depth. Composted manures were applied as a base fertilizer, supplemented with slow-releasing chemical fertilizer (Osmocote NPK 19-6-12) and 1 kg kL water-retaining agent (Han-li-bao Co., Ltd, Beijing). The soil around the planted seedlings was covered with dry grasses to reduce evaporation. Plants were propped with bamboo when growing to 0.5 to 1 m to prevent wind damage. Besides the planting canals test plants were planted: *P. lobata* and *B. corymbosa* were planted at the bottom of the steep and large-scale barren cliff, and *I. enneaphylla*, and *F. tikoua* were applied in greening the slashed land.

Plant height and size were measured at one-month intervals. Three plants of each species were measured. The increases in height (the height from base to bough apical) and size, growth rate and crown diameter (EW ×SN) increase were calculated.

The seedlings were irrigated and fertilized in the first year after planting. They were uncared for and left to grow under natural conditions. During the growing period, the plants were exposed to typhoons and drought for 120 days.

Data treatment

Data of plants' growth were treated in SAS 9.0. Data analysis included means, SD, and differentiation of means by DMRT.

RESULTS

Growth of arbor trees

Tree height

The growth of 4 arbor trees after one year is shown in **Fig. 1**. Their increase in height was less than 2 meters in the first year after planting. *C. tricuspidata* grew the fastest among the four species, followed by *D. toxocarpa*, *F. gibbosa*, and *C. glauca*, in this order (see **Table 3**). Analysis of variance

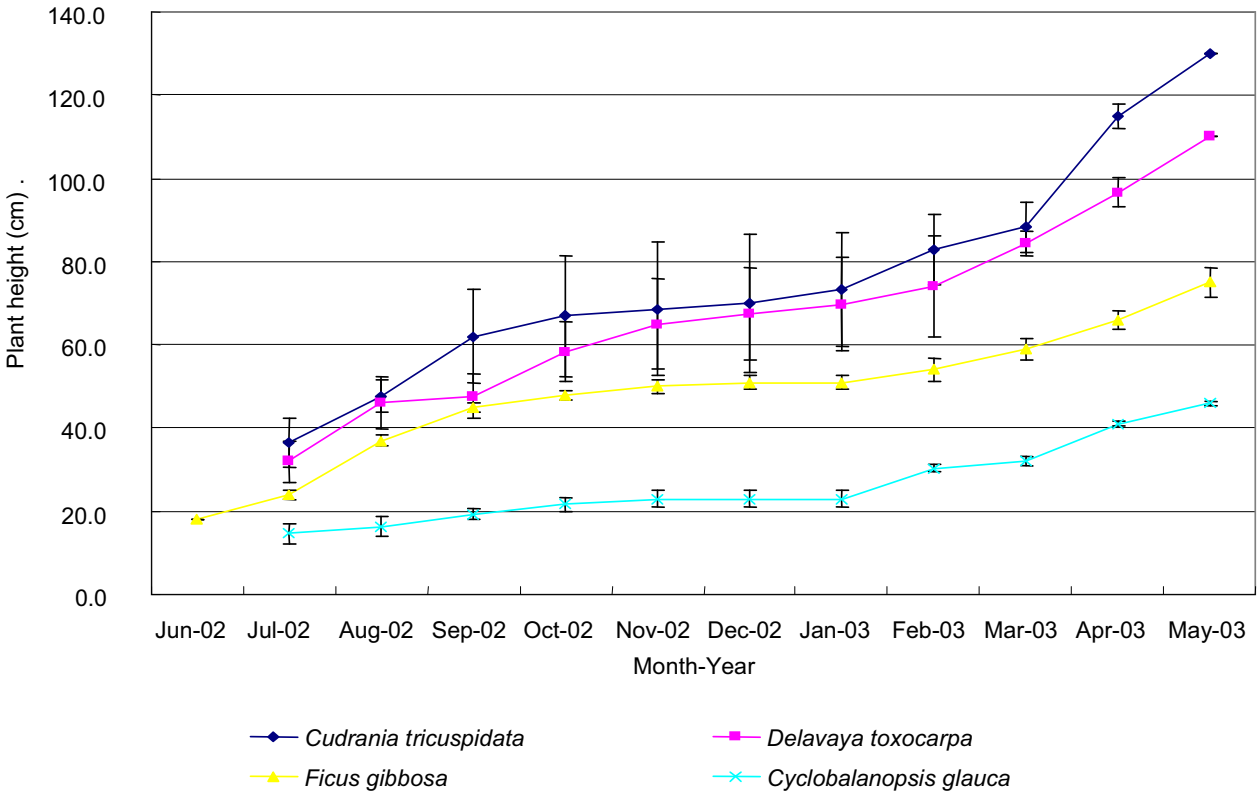

Fig. 1 Monthly growth amount of four arbor tree species.

Table 3 Monthly average growth amount of four arbor tree species.

Species	*Cudrania tricuspidata* (Carr.) Bur.	*Delavaya toxocars* Fr.	*Ficus gibbosa* Bl.	*Cyclobalanopsis glauca* (Thunb.) Oerst.
Monthly average growth (cm/month)	9.367 a	7.800 ab	5.182 bc	3.133 c

Values followed by the same letter are not significantly different (P < 0.05, DMRT).

Table 4 Average amount of growth of arbor tree every month.

month	Mar-03	Apr-03	Jul-02	Aug-02	Jan-03	Jun-02	Feb-03	Sep-02	Oct-02	Nov-02	Dec-02
Growth amount (cm/month)	13.750 a	10.583 ab	10.000 abc	6.750 bcd	6.083 bcd	6.000 bcd	5.583 bcd	5.250 bcd	2.917 cd	1.417 d	1.167 d

Values followed by the same letter are not significantly different (P < 0.05, DMRT).

Table 5 Growth in canopy size of 4 arbor species.

Species	Canopy size (EW × NS, cm^2)											Monthly average (cm^2)
	Month, 2002			Month, 2003								
	7	8	9	10	11	12	1	2	3	4	5	
Gudrania tricuspidata	834	1307	2425	4960	5280	5321	5553	5969	6358	7452	8816	798.2 a
Delavaya toxocarpa	633	700	682	971	1024	1056	1056	1178	1224	2105	2261	162.8 b
Ficus gibbosa	339	339	533	533	533	533	533	533	767	960	1040	70.1 b
Cyclobalanopsis glauca	232	232	239	295	350	350	350	369	369	462	495	26.3 b

EW, the distance from east to west; SN, the distance from north to south.

Table 6 Survival rate of arbor species in abandoned 'Fuyuan' quarry, investigated in January, 2006, three years after planting

Species	Trees planted	Living trees	Survival rate (%)	Rank
Delavaya toxocarpa	46	26	56.52	3
Ficus gibbosa	66	36	54.54	4
Cudrania tricuspidata	108	56	51.85	5
Cyclobalanopsis glauca	37	0	0	

indicated significant differences in the height among species (P = 0.0059, F = 5.18) and months (P = 0.0017, F = 4.08). Growth in March and April was larger than in October, November and December, while there was no significant difference between months from July to February (see **Table 4**). These results are related to climate, when March temperature began to increase, and rainfall and higher humidity also favor planting.

Growth in canopy size

Growth in canopy size is shown in **Table 5**. Among the 17 species, *F. gibbosa* and *C. glauca* grew the slowest, with less than 0.1 m^2 of canopy size increase in one year. There were significant differences among species (P = 0.0002, F = 9.21). Results from DMRT indicate that *C. tricuspidata* (798.2) grew significantly faster than the other three species while there was no difference in growing speed among *D. toxocars* (162.8), *F. gibbosa* (70.1) and *C. glauca* (26.3). If monthly average canopy size increase is calculated, there were no significant differences among months.

Survival rate

Survival rate 3 years after planting is presented in **Table 6**. The survival rate depended on the plants' stress tolerance to drought and barren soil to a certain extent. Plants which not only survive in an adverse environment but also grow normally will be those that best adapt. The survival rate of *D. toxocarpa*, *F. gibbosa* and *C. tricuspidata* was greater than 50% while that of *D. toxocarpa* was the greatest while in *C. glauca* no seedlings survived. This may be attributed to the small size of the seedling and its slow initial growth, and encroachment by other species on its living space.

Growth of bushy species

Annual increase in plant height

Increases in plant height of six bushy species in the first year after planting are shown in **Fig. 2**. The total growth in height was less than 2 m. *F. latifolia* grew the fastest followed in descending order by *P. atalantioides*, *C. cochinchinensis*, *C. cinerascens*, *L. kweilinensis* and *R. spinosa*.

Yearly increase in canopy size

Yearly increases in canopy size of six bushy species are shown in **Table 7**. *F. latifolia* grew the fastest, followed by *C. cochinchinensis*, both with an annual increase of more than 1 m^2. *R. spinosa* grew the slowest with an annual growth of only 0.1 m^2, less than 10% of the two previous species. A significant difference was observed among species (P = 0.0368, F = 2.62) but not among months (P = 0.0570, F = 1.99).

F. latifolia grew the fastest, with an average monthly growth of 1266.1 cm^2, followed by *C. cochinchinensis* (1004.5) *L. kweilinensis* (327.3) and *R. spinosa* (108.5), which grew significantly slower than other species, with an average monthly growth of 110 cm^2 to 300 cm^2.

Survival rate 3 years after planting

Survival rate 3 years after planting is shown in **Table 8**. The survival rate was between 30 and 60%, with the highest in *C. cochinchinensis* and *C. cinerascens*, while no *P. atalantioides* plants survived.

Table 7 Annual increase in canopy size of six bushy species

Species	Increase in canopy size (cm^2)												Monthly average (cm^2)
	Month, 2002						Month, 2003						
	6	7	8	9	10	11	12	1	2	3	4	5	
Flemingia latifolia		663	2441	5005	8550	8921	9574	9771	10457	12040	12705	13324	1266.1 a
Cudrania cochinchinensis	650	650	1679	2698	1935	3130	3294	3406	3651	3999	8150	11700	1044.5 ab
Pyracantha atalantioides		1537	2093	2292	3358	4086	4401	4517	4766	6552	9111	9718	818.1 ab
Cipadessa cinerascens		899	1481	1810	2250	2625	2807	2943	3302	3302	3844	7211	631.2 abc
Lagerstroemia kweilinensis		1486	1736	2463	2463	2514	2564	2564	2564	3440	4266	4759	327.3 bc
Randia spinosa		371	414	432	613	725	738	837	941	1020	1235	1456	108.5 c

Table 8 Survival rate of six bushy species in abandoned 'Fuyuan' quarry, investigated in April, 2006, three years after planting.

Species	Plants	Living plants	Survival rate (%)	Rank
Cudrania cochinchinensis	74	46	62.16	1
Cipadessa cinerascens	52	32	61.54	2
Lagerstroemia kweilinensis	84	42	50.00	6
Randia spinosa	56	24	42.86	7
Flemingia latifolia	10	3	30.00	8
Pyracantha atalantioides	57	0	0	

Growth of climbing bushy species

Increment in plant height

The average yearly growth in seven climbing bushy species is shown in **Fig. 3**. *P. montana* grew the fastest followed by *B. corymbosa*, with a 600 cm increment in one year, while *J. elongatum* (11.867), *B. lineate* (2.636) and *F. dikoua* (3.400) grew the slowest, with less than 100 cm, and *I. enneaphylla* (22.333) and *P. aculeate* (22.467) were in between, with about 300 cm growth. Significant differences were found in annual growth among species ($P < 0.0001$, F = 10.41) but not among months ($P = 0.0385$, F = 2.22).

Coverage of canopy

Monthly growth in canopy in 5 climbing bushes is listed in **Table 9**. Significant differences were found among species ($P < 0.0001$, F = 10.81) and also among months ($P = 0.0202$, F = 2.54). *I. enneaphylla* (5372.6) had the biggest growth followed by *P. aculeate* (3541.2) and *J. elongatum* (1067.0). The main growing months were February (4861) and March (4600) followed by April (3267) and August (2840). There were no significant differences in other seasons.

DISCUSSION

In the past, only simple plant species had been tried and only short-term effects were taken into account in many quarries. For example, grasses or *Cajanus cajan* (L.) Mjlls-paugh are normally applied. After a few years they wither and die. From the above observations, taking into account survival rate and grow increase, positive, encouraging results were obtained for ten wild species: *Cudrania cochinchinensis* (Lour.) Kudo *et* Masam, *Lagerstroemia kweilinensis*, *Cudrania tricuspidata* (Carr.) Bur., *Delavaya toxocarpa* Franch., *Ficus gibbosa* Bl., *Cipadessa cinerascens* (Pell) H.M., *Randia spinosa*, *Pueraria montana* (Lour.) Merr., *Bauhinia corymbosa* Roxb., *Indigofera enneaphylla* L. and *Ficus tikoua* Bureau.

Abandoned quarries or the slopes beside expressways initially have little soil with low water-retaining ability and highly variable diurnal temperatures. When it rains, surface flooding will worsen the subsequent drought. Plants adapt to droughts in various ways, including better water retention by the leaves and a better ability to absorb water through the root systems (Jia *et al*. 2005). After one year's growth,

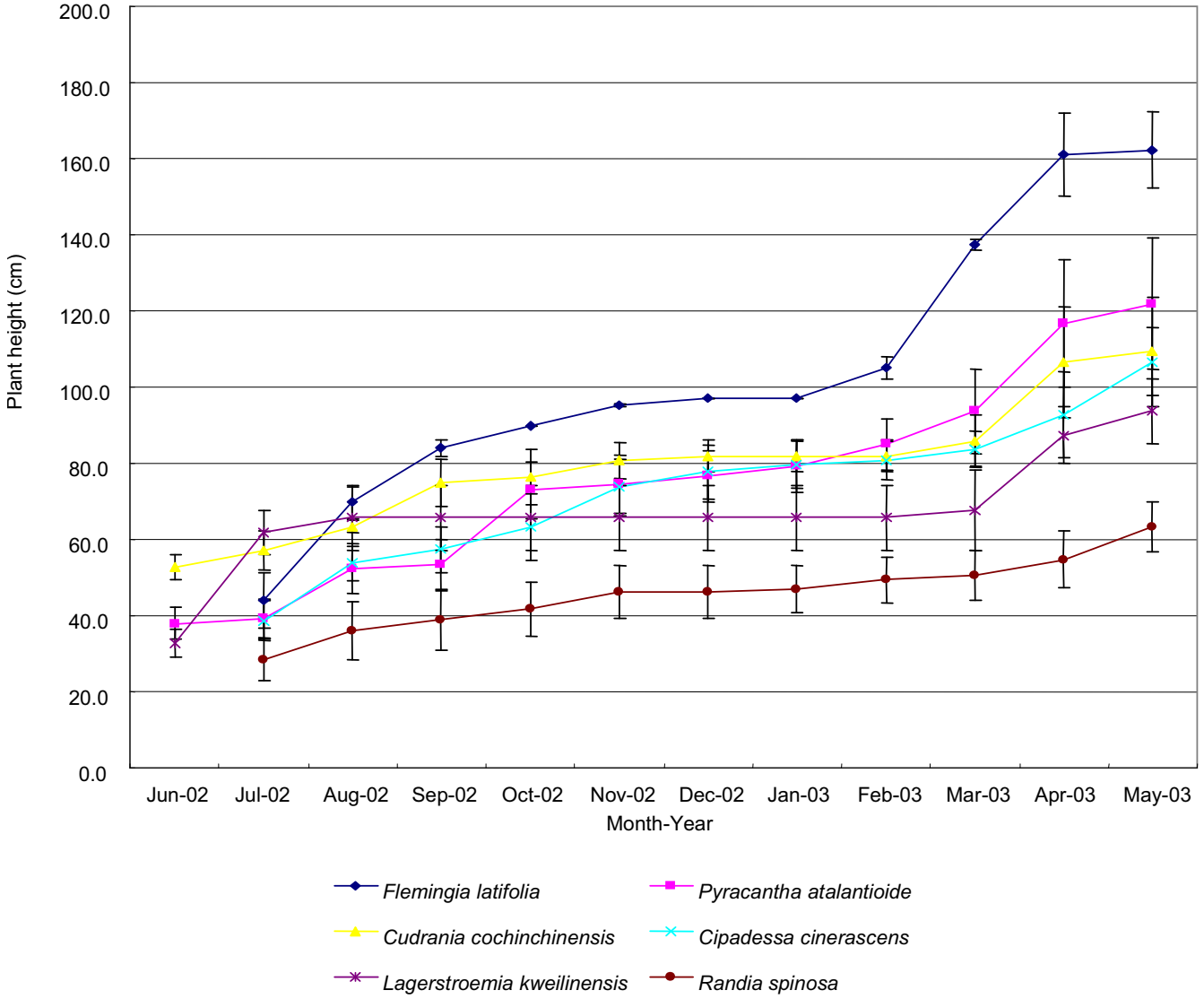

Fig. 2 Growth in plant height of six bushy species.

Table 9 Monthly growth in canopy of five climbing bushy species.

Species	Canopy size increment (cm^2)												Monthly average (cm^2)
	Month, 2002		Month, 2003										
	6	7	8	9	10	11	12	1	2	3	4	5	
Indigofera enneaphylla	3721	3762	8358	14240	18807	23102	26027	31389	36261	42972	55875	62820	5372.6 a
Pereskia aculeate			4494	10784	11166	11484	12106	12141	12141	25537	31160	36365	3541.2 a
Jasminum elongatum		371	828	1328	2438	2906	2925	3038	3038	3920	7650	11040	1066.9 b
Berchemia lineata	945	945	1700	2128	2508	2588	2684	2684	2999	5928	6270	6869	538.5 b
Ficus tikoua			700	1136	1488	1674	1697	2091	2138	2381	2516	2580	208.9 b

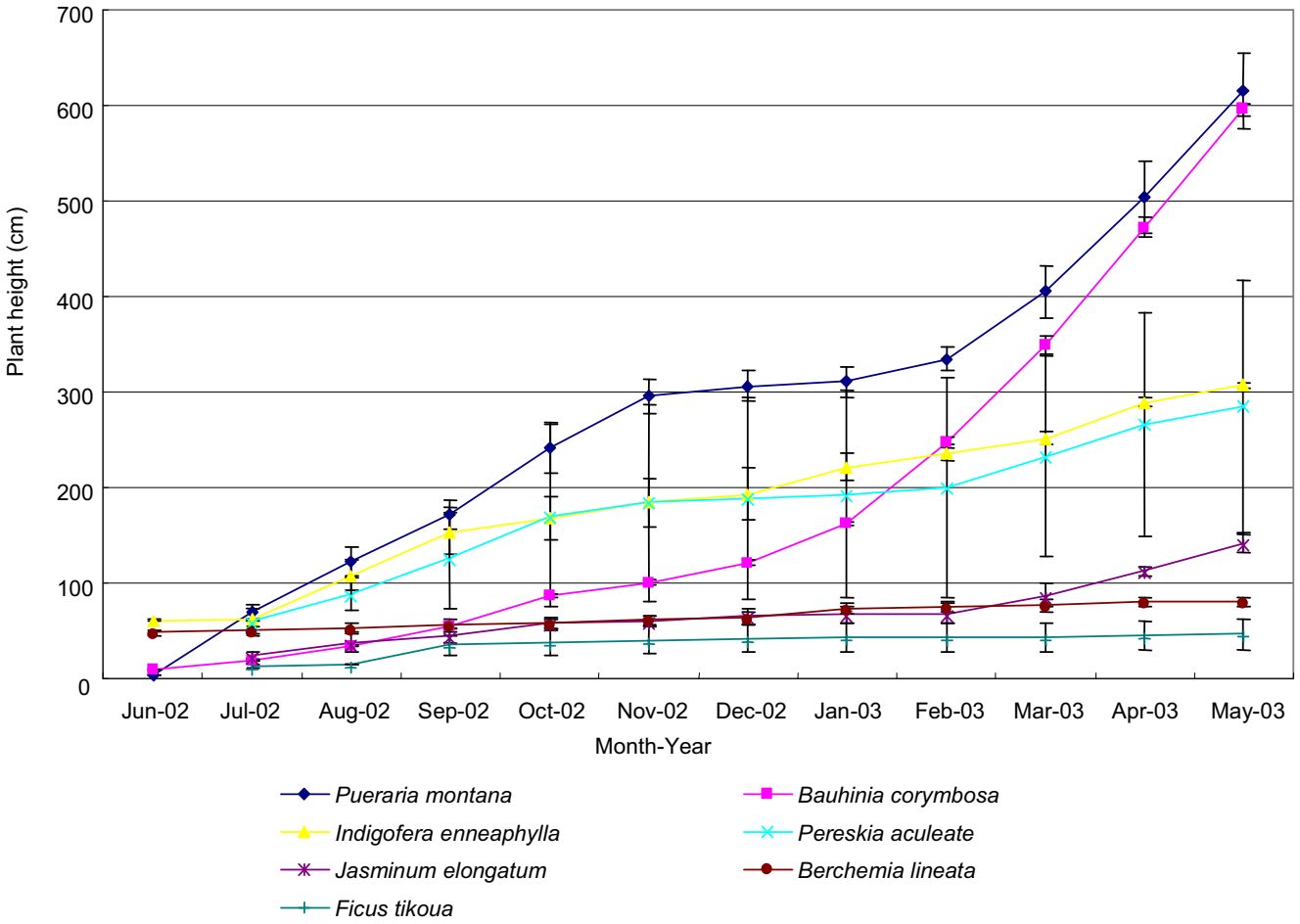

Fig. 3 Plant height increment in one year after planting in 7 climbing bushy species

Ficus gibbosa grew to 2.7 cm (ground diameter) and 2 to 3 m in height, showing a good adaptability and fast growing character. *D. toxocarpa* grew slanted, up to 2.3 cm in ground diameter and 2 to 3 m in height, while *C. tricuspidata* was 2.4 cm thick and 3.2 to 3.5 m tall, although it spread more slowly than *C. cochinchinensis*. The growths are sufficient to afforest abandoned quarries.

F. gibbosa has a strong root system and is very tolerant to drought. The plant is able to grow among dry and barren rocks, however it grows slowly. *D. toxocarpa* is tolerant to drought and barren conditions, and is able to grow fast in holes in rocks, torclinosol and rock apertures, etc. In this experiment, the yearly growth of *D. toxocarpa* reached 78 cm, which was 2.5 times its original height. *C. tricuspidata* also has a deep, thick and strong main root and lateral roots and is very drought tolerant.

C. cochinchinensis has a strong root system, is tolerant to drought with no strict requirement for soil type. The plant is able to grow in calciferous and acid soils. *Lagerstroemia kweilinensis* likes sunlight, is tolerant to drought and barren conditions, with good adaptability in the root system. *Cipadessa cinerascens* is neutral in sunlight demand and is able to grow in rocky mountains. *Flemingia latifolia* Beth. grew the fastest among the bushy species tested because of its strong root system. It grew 118.3 cm in height in one year.

Based on our results, *P. montana* and *B. corymbosa* are most suitable for afforesting cliffs and rocky slopes, while *I. enneaphylla*, and *F. tikoua* are better for flat, rocky areas.

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