Q_{10} values of soil respiration in Japanese forests

SHOJI HASHIMOTO

Forestry & Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki, 305-8687, Japan

shojih@ffpri.affrc.go.jp

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Q_{10} is the most important index of soil respiration, which is essential for accurate prediction of soil carbon response to global warming. The response of soil carbon storage is an issue of both global and each country's scales. In this study published Q_{10} values of soil respiration in Japanese forests were examined (n=44). The Q_{10} values ranged from 1.30 to 3.45, and the mean value was 2.18 (SD=0.61, median=2.02). These results were slightly smaller than those of global compilations. The number of studies is still lacking, especially, studies in managed forest, investigations in northeast Japan, and results measured using recent equipment (e.g. IRGA). For accurate prediction of soil carbon dynamics and storage in Japanese forests, more studies and their synthesis are strongly required.

Keywords: soil respiration, Q_{10}, temperature sensitivity, climate change, Japanese forest

Introduction

Q_{10} is the most important property of soil respiration, which is a widely used index of temperature sensitivity of soil respiration and is the factor by which the respiration rate differs for a temperature interval of 10 °C. Because soil respiration is strongly controlled by soil temperature and exponentially increases with increasing soil temperature (e.g. Howard and Howard 1993; Raich and Potter 1995; Ohashi et al. 1999; Leirós et al. 1999; Zak et al. 1999; Schlesinger and Andrews 2000; Rustad et al. 2000; Fang and Moncrieff 2001), different Q_{10} values result in very different predictions of soil carbon dynamics and its storage. For example, it is predicted that global land carbon storage may significantly increase or may hardly increase depending on Q_{10} values (Lenton and Huntingford 2003). Although some recent studies claim the difficulty of comparing Q_{10} values (e.g. Davidson et al. 2000; Morén and Lindroth 2000; Janssens and Pilegaard 2003; Bååth and Wallander 2003; Yuste et al. 2004), Q_{10} is still a very informative index for predicting soil carbon dynamics and its storage.

The response of soil carbon is a global issue; at the same time, it is a regional and local issue for each country (IGBP 1998; Schulze et al. 2000, 2002). Kyoto protocol, which assigns the decrease of CO_2 emission to each country, finally came into effect. Biological carbon sequestration, especially, sink of carbon by forest including forest soil, can be counted for the decrease. The response of soil carbon in each country is therefore very important even though the contribution would be globally small.

However, it is unclear whether forest biome (plant and soil) is a sink or source of carbon, and how much carbon forests can sequestrate if possible (Cao and Woodward 1998; Grace and Rayment 2000; Kirschbaum 2000; Rustad et al. 2000; Schlesinger and Andrews 2000; Schulze et al. 2000; Nemani et al. 2003; Powlson 2005). For accurate assessments of soil carbon response in Japanese forests, first of all, it is essential to compile data of Q_{10} values in Japanese forests. There are several review papers which globally compiled Q_{10} values (e.g. Raich and Schlesinger 1992; Lenton and Huntingford 2003); however, there is no compilation of Q_{10} values of Japanese forests. The object of this study is to examine the range and the mean value of Q_{10} in Japanese forests.

Data

I collected published Q_{10} values which were measured in Japanese forests.

Table 1 in Appendix 2 shows the data used in this study and their sources.
The northern limit was at Hokkaido prefecture (42°44'N; Liang et al. 2004), and the southern limit was Kumamoto prefecture (32°10'N; Yoneda and Kirita 1978). When several values were reported at a same site but different plots, I averaged them and used the value. In some studies which investigated temperature sensitivity of soil respiration, Q_{10} values were not calculated; they reported only fitted functions. Then I calculated Q_{10} values using these relationships reported (see Appendix 1).

Results and Discussion

Figure

Figure 1 presents the histogram of Q_{10} values of Japanese forests, which includes results of both in fields and laboratories. The Q_{10} values ranged from 1.30 to 3.45, and the mean value was 2.18 (SD=0.61, median=2.02, n=44).
The Q_{10} values measured in fields ranged from 1.30 to 3.17, and the mean value was 2.12 (SD=0.56, n=40).Those in laboratories ranged from 1.56 to 3.45, and the mean value was 2.73 (SD=0.85, n=4). In most studies, the alkali absorption method was used; however, recent studies showed the difference between the results measured by the alkali absorption method and that using IRGA (Davidson et al. 2000, 2002; Hashimoto et al. 2004). Then the mean value of Q_{10} measured using IRGA in fields was calculated (Ohashi et al. 1999, 2000; Lee et al. 2002; Yim et al. 2002; Mizogichi et al. 2003; Hirano et al. 2003; Mitani et al. 2003; Liang et al. 2004; Takahashi et al. 2004; Nobuhiro et al. 2004). The mean value of those measured by IRGA was 2.36 (SD=0.51, n=12). Although the number of reports was small (n=12), and it was not statistically significant, the value, in fact, tended to be larger than that measured by the alkali absorption method in fields (mean=2.02, n=27, $p>0.05$); more studies using IRGA are needed.
The overall mean and median obtained in this study were slightly smaller than those of global; Raich and Schlesinger (1992) reported the median value of 2.4, and Lenton and Huntingford (2003) reported the mean value of 2.54 in fields, and 2.51 in laboratories, which was the value of an extension of the compilation of Raich and Schlesinger (1992) with some more reported values. The range obtained were smaller than those reported (Lenton and Huntingford 2003); they reported Q_{10} values in fields ranged from 1.3 to 5.6, and those in laboratories ranged from 0.8 to 12.92.
This study compiled 44 data; however, forest types were still limited considering that Japan extends long from north to south and has various vegetations. Also, Q_{10} values may differ depending on the latitude even in the same forest types (e.g. between *Cryptomeria japonica* plantation in Aomori prefecture and that in Kagoshima prefecture). So far the number of measurements was too small to analyze them in detail. In particular, this study showed that following studies are lacking. Firstly, studies in managed forest (or artificial forest) are not enough, in spite of the fact almost a half of the forest in Japan is artificial forest, and managed forest is crucial for Kyoto Protocol. Secondly, studies in northeast Japan are absent. Thirdly, studies using recent equipment (e.g. IRGA) are needed. For accurate prediction of soil carbon dynamics and storage in Japanese forests, more studies and their synthesis are strongly required.

Appendix 1

Q_{10} values were not directly reported in some studies. Then Q_{10} values were calculated as follows.
Some studies reported only exponential fitted curves (Chiba and Tsutsumi 1967; Nakane 1975, 1978, 1995; Takai et al. 1977; Nakane et al. 1984; Katagiri 1988; Lee et al. 2002): y(T)=A exp(kT); where y(T) is the soil respiration, T is the soil temperature and A and k are fitted parameters, respectively.
Then, Q_{10} values were calculated by the following equation:

$$Q_{10}=\exp(10k).$$

In a study (Ino and Monsi 1969), temperature sensitivity of soil CO_2 production was fitted with a quadratic equation with other factors as follows:

$$y(T)=p\ g(T)\ f(x)$$

where p is a fitted parameter, g(T) is a relationship with T, and f(x) is a relationship with other factors like soil carbon content or water content.
g(T) was described as follows:

$$g(T)=(T^2+qT+r)$$

where q and r are fitted parameters.
Average temperature (T_{ave}) in the field where samples were collected were reported as well.
Then Q_{10} values were calculated with the ratio of $y(T_{ave}+5)$ to $y(T_{ave}-5)$ as follows:

$$Q_{10}=y(T_{ave}+5)/y(T_{ave}-5)$$

$$=g(T_{ave}+5)/g(T_{ave}-5)$$

$$=((T_{ave}+5)^2+q(T_{ave}+5)+r)/((T_{ave}-5)^2+q(T_{ave}-5)+r)$$

Q_{10} values at each site were averaged .
They incubated soil sample at 10, 20, and 30 °C at 4 forested sites; however, average temperature at the 2 sites were beyond the incubation range. Hence the results of these two were not included in this study.

Appendix 2

Table 1: Q_{10} values in Japanese forests.

Table

Literature cited

Bååth E, Wallander H (2003) Soil and rhizosphere microoganisms have the same Q_{10} for respiration in a model system. Global Change Biology 9: 1788-1791

Cao M, Woodward FI (1998) Dynamic responses of terrestrial ecosystem carbon cycling to global climate change. Nature 393: 249-252

Chiba K, Tsutsumi T (1967) A study on the soil respiration of forests (1) The relationships between the soil respiration and air temperature. Bulletin of Kyoto University Forest 39: 91-99 (in Japanese with English summary)

Davidson EA, Savage K, Bolstad P, Clark DA, Curtis PS, Ellsworth DS, Hanson PJ, Law BE, Luo Y, Pregitzer KS, Randolph JC, Zak D (2002) Belowground carbon allocation in forests estimated from litterfall and IRGA-based soil respiration measurements. Agricultural and Forest Meteorology 113: 39-51

Davidson EA, Verchot LV, Cattanio JH, Ackerman IL, Carvalho JEM (2000) Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. Biogeochemistry 48: 53-69

Fang C, Moncrieff JB (2001) The dependence of soil CO_2 efflux on temperature. Soil Biology and Biochemistry 33: 155-165

Grace J, Rayment M (2000) Respiration in the balance. Nature 404: 819-820

Hashimoto S, Tanaka N, Suzuki M, Inoue A, Takizawa H, Kosaka I, Tanaka K, Tantasirin C, Tangtham N (2004) Soil respiration and soil CO_2 concentration in a tropical forest, Thailand. Journal of Forest Research 9: 75-79

Hirano T, Kim H, Tanaka Y (2003) Long-term half-hourly measurement of soil CO_2 concentration and soil respiration in a temperate deciduous forest. Journal of Geophysical Research 108: 4631-4644

Howard DM, Howard PJA (1993) Relationships between CO_2 evolution, moisture content and temperature for a range of soil types. Soil Biology and Biochemistry 25: 1537-1546

Hu R, Kusa K, Hatano R (2001) Soil respiration and methane flux in adjacent forest, grassland, and cornfield soils in Hokkaido, Japan. Soil Science and Plant Nutrition 47: 621-627

IGBP TCWG (1998) The terrestrial carbon cycle: Implications for the Kyoto Protocol. Science 280: 1393-1394

Ino Y, Monsi M (1969) An experimental approach to the calculation of CO_2 amount evolved from several soils. Japanese Journal of Botany 20: 153-188

Janssens IA, Pilegaard K (2003) Large seasonal changes in Q_{10} of soil respiration in a beech forest. Global Change Biology 9: 911-918

Katagiri S (1988) Estimation of proportion of root respiration in total soil respiration in deciduous broadleaved stands. Journal of Japanese Forest Society 70: 151-158 (in Japanese with English summary)

Kirita H (1971) Studies of soil respiration in warm-temperate evergreen broadleaf forests of southwestern Japan. Japanese Journal of Ecology 21: 230-244 (in Japanese with English summary)

Kirschbaum MUF (2000) Will changes in soil organic carbon act as a positive or negative feedback on global warming? Biogeochemistry 48: 21-51

Lee M-S, Nakane K, Nakatsubo T, Mo W-H, Koizumi H (2002) Effects of rainfall events on soil CO_2 flux in a cool temperate deciduous broad-leaved forest. Ecological Research 17: 401-409

Leirós MC, Transar-Cepeda C, Seoane S, Gil-Sotres F (1999) Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biology and Biochemistry 31: 327-335

Lenton TM, Huntingford C (2003) Global terrestrial carbon storage and uncertainties in its temperature sensitivity examined with a simple model. Global Change Biology 9: 1333-1352

Liang N, Nakadai T, Hirano T, Qu L, Koike T, Fujinuma Y, Inoue G (2004) In situ comparison of four approaches to estimating soil CO_2 efflux in a northern larch (*Larix kaempheri* Sarg.) forest. Agricultural and Forest Meteorology 123: 97-117

Mitani T, Kosugi Y, Tani M, Takahashi S, Katayama T, Wada T (2003) Spatial and temporal variation of soil respiration rate in an artificial forest of Hinoki (*Chamaecyparis obtusa*). Journal of the Japanese Society of Revegetation Technology 29: 153-158 (in Japanese with English summary)

Mizogichi Y, Ohtani Y, Watanabe T, Yasuda Y, Okano M (2003) Long-term continuous measurement of CO_2 efflux from a forest floor using dynamic closed chambers with automatic opening/closing capability. Japanese Journal of Ecology 53: 1-12 (in Japanese with English summary)

Morén A-S, Lindroth A (2000) CO_2 exchange at the floor of a boreal forest. Agricultural and Forest Meteorology 101: 1-14

Nakane K (1975) Dynamics of soil organic matter in different parts on a slope under evergreen oak forest. Japanese Journal of Ecology 25: 206-216 (in Japanese with English summary)

Nakane K (1978) Dynamics of soil organic carbon and its seasonal variation in a cool-temperate beech/fir forest on Mt. Odaigahara. Japanese Journal of Ecology 28: 335-346 (in Japanese with English summary)

Nakane K (1995) Soil carbon cycling in a Japanese cedar (*Cryptomeria japonica*). Forest Ecology and Management 72: 185-197

Nakane K, Tsubota H, Yamamoto M (1984) Cycling of soil carbon in a Japanese Red Pine forest I. Before a clear-felling. The Botanical Magazine, Tokyo 97: 39-60

Nakane K, Yamamoto M, Tsubota H (1983) Estimation of root respiration rate in a mature forest ecosystem. Japanese Journal of Ecology 33: 397-408

Nemani RR, Keeling CD, Hashimoto H, Jolly WM, Piper SC, Tucker CJ, Myaneni RB, Running SW (2003) Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science 300: 1560-1563

Nobuhiro T, Tamai K, Kominami Y, Miyama T, Goto Y, Kanazawa Y (2004) Development of the IRGA enclosed-chamber system for soil CO_2 efflux measurement and its application to a spatial variation measurement. Journal of Forest Research 8: 297-301

Ohashi M, Gyokusen K, Saito A (1999) Measurement of carbon dioxide evolution from a Japanese cedar (*Cryptomeria japonica* D. Don) forest floor using an open-flow chamber method. Forest Ecology and Management 123: 105-114

Ohashi M, Gyokusen K, Saito A (2000) Contribution of root respiration to total soil respiration in a Japanese cedar (*Cryptomeria Japonica* D. Don) artificial forest. Ecological Research 15: 323-333

Powlson D (2005) Will soil amplify climate change? Nature 433: 204-205

Raich JW, Potter CS (1995) Global patterns of carbon dioxide emissions from soils. Global Biogeochemical Cycles 9: 23-36

Raich JW, Schlesinger WH (1992) The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus 44B: 81-99

Rustad LE, Huntington TG, Boone RD (2000) Controls on soil respiration: Implications for climate change. Biogeochemistry 48: 1-6

Sakai M, Tsutsumi T (1987) Carbon cycles of two different soil types in a cool-temperate forest in Japan (II) Seasonal variations of soil respiration rates under the effects of soil environmental factors. Journal of Japanese Forest Society 69: 41-48 (in Japanese with English summary)

Schlesinger WH, Andrews JA (2000) Soil respiration and the global carbon cycle. Biogeochemistry 48: 7-20

Schulze E-D, Valentini R, Sanz M-J (2002) The long way from Kyoto to Marrakesh: Implications of the Kyoto Protocol negotiations for global ecology. Global Change Biology 8: 505-518

Schulze E-D, Wirth C, Heimann M (2000) Managing forests after Kyoto. Science 289: 2058-2059

Shimono T, Takeda H, Iwatsubo G, Tsutsumi T (1989) Seasonal changes in soil respiration rates from the floor of *Chamaecyparis obtusa* and *Cryptomeria japonica* plantations. Bulletin of Kyoto University Forest 61: 46-59 (in Japanese with English summary)

Takahashi A, Hiyama T, Takahashi HA, Fukushima Y (2004) Analytical estimation of the vertical distribution of CO_2 production within soil: application to a Japanese temperate forest. Agricultural and Forest Meteorology 126: 223-235

Takai Y, Kanazawa S, Wada H, Asami T, Takeuchi H, Takeshima S (1977) Decomposition processes of organic matter in the soil. In: Kitazawa Y (ed) Ecosystem analysis of the subalpine coniferous forest of the Shigayama IBP area, central Japan, JIBP Synthesis 15. University of Tokyo Press, Tokyo, pp 167-179

Yim MH, Joo SJ, Nakane K (2002) Comparison of field methods for measuring soil respiration: a static alkali absorption method and two dynamic closed chamber methods. Forest Ecology and Management 170: 189-197

Yoneda T, Kirita H (1978) Soil respiration. In: Kira T, Ono Y, Hosokawa T (eds) Biological production in a warm-temperate evergreen oak forest of Japan, JIBP Synthesis 18. University of Tokyo Press, Tokyo, pp 239-249

Yuste JC, Janssens IA, Carrare A, Ceulemans R (2004) Annual Q_{10} of soil respiration reflects plant phenological patterns as well as temperature sensitivity. Global Change Biology 10: 161-169

Zak DR, Holmes WE, MacDonald NW, Pregitzer KS (1999) Soil temperature, matric potential, and the kinetics of microbial respiration and nitrogen mineralization. Soil Science Society of America Journal 63: 575-584

Figures

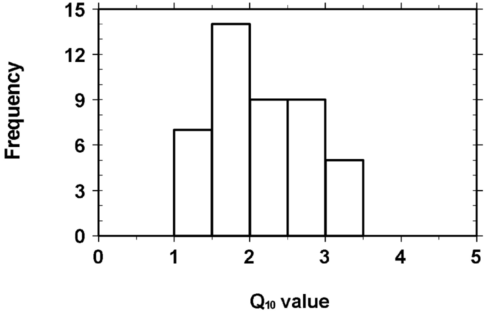
Figure 1: Histogram of Q_{10} values for soil respiration in Japanese forests.

Q_{10}	Vegetation	Prefecture	Location	Elevation	Reference
	In fields.				
1.36[h]	*Cryptomeria japonica*	Kyoto	35°16-21'N, 135°42-47'E [b]	355-959 [b]	Chiba and Tsutsumi 1967
1.35[h]	(Deciduous Broad-leaved)	Kyoto	35°16-21'N, 135°42-47'E [b]	355-959 [b]	Chiba and Tsutsumi 1967
1.35[h]	*Picea excelsa*	Kyoto	35°16-21'N, 135°42-47'E [b]	355-959 [b]	Chiba and Tsutsumi 1967
1.36[h]	*Quercus crispula*	Kyoto	35°16-21'N, 135°42-47'E [b]	355-959 [b]	Chiba and Tsutsumi 1967
1.34[h]	*Cryptomeria japonica, Fagus crenata*	Kyoto	35°16-21'N, 135°42-47'E [b]	355-959 [b]	Chiba and Tsutsumi 1967
1.34[h]	*Chamaecyparis obtusa*	Kyoto	35°4'N, 135°46'E [b]	109-225 [b]	Chiba and Tsutsumi 1967
1.30[ah]	*Pinus densiflora*	Kyoto	35°4'N, 135°46'E [b]	109-225 [b]	Chiba and Tsutsumi 1967
2.70[jkl]	*Quercus mongolica, Magnolia obovata, Ulmus davidiana, Acer mono, Carpinus cordata*	Hokkaido	42°4'N, 141°4'E	70	Hirano et al. 2003
1.92	*Aceraceae rubrum, Fagaceae quercus*	Hokkaido	42°25.9'N, 142°29.1'E	-	Hu et al. 2001
1.52[ah]	*Quercus serrata, Castanea crenata*	Shimane	35°9'N, 132°4'E [b]	300-624 [b]	Katagiri 1988
2.86	*Castanopsis cuspidata, Quercus salicina, Quercus gilva, Carpinus laxiflora*	Nara	34°40'N, 135°52'E [b]	283 [b]	Kirita 1971
3.10[hl]	*Quercus crispula* Blume, *Betula ermanii* Cham	Gifu	36°08'N, 137°26'E	1430	Lee et al. 2002
2.33[alm]	*Larix kaempheri* Sarg., *Picea jezoensis* Sieb. Et Zucc., *Betula* spp.	Hokkaido	42°44'N, 141°31'E	125	Liang et al. 2004
1.58[al]	*Chamaecyparis obtusa*	Shiga	34°58'N, 136'E	-	Mitani et al. 2003
2.80[afl]	*Quercus serrata* Thunb, *Carpinus laxiflora* Blume, *Ilex macropoda* Miq., *Clethra barvinervis* Sieb. et Zucc.	Saitama	35°9'N, 139°5'E	30	Mizoguchi et al. 2003
2.59[h]	*Symplocos prunifolia, Pieris japonica*	Nara	34°40'N, 135°52'E [b]	300-350	Nakane 1975
2.80[h]	*Pieris japonica, Quercus sessilifolia, Castanopsis cuspidata, Symplocos prunifolia*	Nara	34°40'N, 135°52'E [b]	300-350	Nakane 1975
2.89[h]	*Quercus sessilifolia, Castanopsis cuspidata, Cleyera japonica,*	Nara	34°40'N, 135°52'E [b]	300-350	Nakane 1975

	Eurya japonica				
3.17[gh]	*Fagus crenata, Abies homolepis*	Nara	34°12'N, 136°06'E [b]	1490	Nakane 1978
2.36[h]	*Cryptomeria japonica*	Hiroshima	34°25'N, 132°3'E	440-450	Nakane 1995
2.01[dh]	*Cryptomeria japonica*	Hiroshima	34°25'N, 132°3'E	440-451	Nakane 1995
2.45[h]	*Pinus densiflora*	Hiroshima	34°24'N, 132°3'E [b]	80-120	Nakane et al. 1983
1.78[ch]	*Pinus densiflora*	Hiroshima	34°24'N, 132°3'E [b]	80-120	Nakane et al. 1983
2.35[ah]	*Pinus densiflora*	Hiroshima	34°24'N, 132°31'E	80-230	Nakane et al. 1984
1.95[adh]	*Pinus densiflora*	Hiroshima	34°24'N, 132°31'E	80-230	Nakane et al. 1984
2.03[al]	(Secondary Broadleaved deciduous)	Kyoto	34°47'N, 135°50'E	-	Nobuhiro et al. 2003
2.00[el]	*Cryptomeria japonica*	Kumamoto	32°49'N, 130°44'E	-	Ohashi et al. 1999
2.50[al]	*Cryptomeria japonica*	Kumamoto	32°49'N, 130°44'E	-	Ohashi et al. 1999
1.85[ael]	*Cryptomeria japonica*	Kumamoto	32°49'N, 130°44'E	-	Ohashi et al. 2000
1.80[al]	*Cryptomeria japonica*	Kumamoto	32°49'N, 130°44'E	-	Ohashi et al. 2000
2.33	*Quercus crispula, Hamamelis japonica* var. obtusata, *Lyonia elliptica, Rhus trichocarpa*	Kyoto	35°18'N, 135°45'E	750	Sakai and Tsutsumi 1987
1.85	*Pterocarya rhoifolia, Fagus crenata, Cornus controversa*	Kyoto	35°18'N, 135°45'E	700	Sakai and Tsutsumi 1987
1.90[a]	*Chamaecyparis obtusa*	Kyoto	35°00'N, 135°49'E [b]	115-125	Shimono et al. 1989
1.76[a]	*Chamaecyparis obtusa*	Kyoto	35°00'N, 135°49'E [b]	115-125	Shimono et al. 1989
2.00[a]	*Cryptomeria japonica*	Kyoto	35°00'N, 135°49'E [b]	115-125	Shimono et al. 1989
2.55[l]	*Quercus variabilis, Quercus. serrata*	Nagoya	35°9'N, 136°54'E [b]	0	Takahashi et al. 2004
2.18	*Quercus serrata* Thunb	Hiroshima	34°3'N, 132°55'E	700	Yim et al. 2002
3.11[alm]	*Quercus serrata* Thunb	Hiroshima	34°3'N, 132°55'E	700	Yim et al. 2002
2.62[a]	*Castanopsis cuspidata*	Kumamoto	32°10'N, 130°28'E	400-637	Yoneda and Kirita 1978
1.76[ai]	*Castanopsis cuspidata*	Kumamoto	32°10'N, 130°28'E	400-637	Yoneda and Kirita 1978
	In laboratories.				
3.45[ah]	*Pinus Thunbegii*	Chiba	35°37'N, 140°7'E [b]	10	Ino and Monsi 1969
2.67[ah]	*Pinus Thunbegii*	Chiba	35°15'N, 139°5'E [b]	0	Ino and Monsi 1969
1.56[h]	*Quercus serrata, Castanea crenata*	Shimane	35°9'N, 132°4'E [b]	300-624 [b]	Katagiri 1988
3.25[a]	*Fagus crenata, Quercus crispula, Betula platyphylla*	Nagano	36°40'N, 138°3'E	1970	Takai et al. 1988

[a] Averaged by the author.
[b] Not reported in the paper. Added by the author.
[c] Data after felling.
[d] A_0 layer was removed.
[e] Thinned.
[f] Temperatures at several depths were compared, and several Q_{10} values were reported. This is the value of 10 cm temperature.
[g] Temperatures at several depths were compared, and several Q_{10} values were reported. This is the value of soil surface temperature.

[h] Calculated from fitted parameters (see Appendix 1).
[i] Daily relationship.
[j] Top soil.
[k] Temperatures at several depths were compared, and several Q_{10} values were reported. This is the value of 0.02 m temperature.
[l] Measured using IRGA.
[m] Average of results by several methods.


15
12
9
6
3
0
Frequency
0
1
2
3
4
5
Q10 value