

REVIEW

New Soil Maps of Japan based on the Comprehensive Soil Classification System of Japan – First Approximation and its Application to the World Reference Base for Soil Resources 2006

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Abstract

This paper reviewed the delineation of a new 1:200,000 national soil map and a 1:50,000 cultivated soil map in Japan based on the Comprehensive Soil Classification System of Japan – First Approximation (CSCJ) and the World Reference Base for Soil Resources 2006 (WRB2006). These new CSCJ soil maps were compared with the 1:200,000 National Land Survey (NLS) soil map and the 1:50,000 cultivated soil map classified by the Classification System for Cultivated Soils revised 2nd Approximation (2nd CSCS) previously published. The distribution area of Andosols, Brown Forest soils, and Red Yellow soils great groups in the NLS soil map, and that of the Andosols, Lowland soils, and Yellow soils groups in the 2nd CSCS cultivated soil map were changed. These new soil maps easily identified the soil profiles and characteristics from the soil name because the CSCJ adopted precise diagnostic criteria, keying rules, and new soil groups that introduced new knowledge on soil pedogenesis into the NLS soil map and the 2nd CSCS cultivated soil map. Then, the national soil map classified by WRB2006 was delineated from the CSCJ national soil map, and Cambisols were mostly distributed in this map. By using numerous soil data from previously conducted studies in Japan, this soil map could accurately represent the distribution of Japanese soils compared with SoilGrid250m that was published recently and is one of the digital world soil maps. In conclusion, these new soil maps will be useful for the management of agricultural land and for environmental analyses at national and regional scales, and they are consistent with international classification systems, making them suitable for global soil information-sharing through schemes such as the FAO's Global Soil Partnership.

Discipline: Soils, fertilizers and plant nutrition

Additional key words: Andosols, Cambisols, Digital soil map, Fundamental Soil Survey for Soil Fertility Conservation, National Land Survey

Introduction

The Food and Agriculture Organization of the

United Nations (FAO) established the Global Soil Partnership (GSP) in 2012. The GSP was established on five pillars of action with the following themes: (1) soil

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management; (2) awareness raising; (3) research; (4) information and data; and (5) harmonization (GSP 2012). The main aim of Pillar 4 is to “provide a common soil data and information platform responding to various users’ needs at global, regional, national and local scales,” such as the Digital Soil Map of the World (GSP 2014). Digital soil maps have been used for various research efforts, such as estimating the distributions of soil organic carbon stock (de Brogniez et al. 2015, Nanko et al. 2017) and soil erosion (Panagos et al. 2014, 2015). Digital soil maps are an essential resource for sharing soil information and resolving environmental problems.

In Japan, two sets of digital soil maps have been published. One is the National Land Survey (NLS) soil map (1:200,000 and 1:500,000), which covers the whole country and is available on the website of the Ministry of Land, Infrastructure, Transport and Tourism (<http://nrb-www.mlit.go.jp/kokjo/inspect/landclassification/download/>). The other is the 1:50,000 Cultivated Soil Map of Japan, which is published by the National Institute for Agro-Environmental Sciences (Takata et al. 2009, Takata et al. 2011).

The digital 1:200,000 NLS soil map is a digitized version of the national soil maps published by NLS during the period 1970-1979. The NLS soil maps were delineated using the cultivated soil maps and forest soil maps, which were prepared separately using different soil classifications (the Classification System for Cultivated Soils revised 2nd Approximation [2nd CSCS; Third Division of Soils 1983] and the Classification of Forest Soils in Japan [1975] [Forest Soil Division 1976]) to facilitate management of each land use (agriculture and forestry) (National Committee for Soil Science and Plant Nutrition, Science Council of Japan 2004). The same soil could therefore be classified by a different name under different land uses, which is clearly a problem when extending soil-based information across the landscape for purposes other than forest or agricultural management. Subsequently, the Fourth Committee for Soil Classification and Nomenclature of the Japanese Society of Pedology created the Unified Soil Classification System of Japan - 2nd Approximation (USCJ; Japanese Society of Pedology 2003). Although the USCJ was independent of land use, it was not suited to preparing large-scale soil maps because the soil types were not defined in a way that enabled the mapping unit to be divided into a lower category than soil subgroups (i.e., soil series groups). Although a national soil map based on this classification was created (Kanno et al. 2008), major parts of the map were simply translated from the NLS soil map, and the map was not digitized. This map is therefore not readily applicable to environmental analysis

in the various patterns of land use from watershed and national scales, such as soil carbon inventory.

The digital cultivated soil map is a digitized version of the cultivated soil maps prepared by the Fundamental Soil Survey for Soil Fertility Conservation during the period 1959-1976. However, the mapping units were based on 2nd CSCS. Subsequently, the 3rd CSCS (Cultivated Soil Classification Committee 1995) was published to meet increasing demands for soil classification and soil maps to contribute to the environmental sciences and to reflect the ongoing accumulation of soil information. However, no digital soil map based on this classification system has yet been made available. Therefore, the only digitally published cultivated soil map, based on the 2nd CSCS, did not reflect the new information on soil genesis that was incorporated into the 3rd CSCS, such as the Non-allophanic Andosols, which require careful management because of their strong acidity (Kubotera et al. 2015).

Therefore, Obara et al. (2011) published the Comprehensive Soil Classification System of Japan – First Approximation (CSCJ). This classification system integrated the USCJ and 3rd CSCS, so it enabled soils to be classified independently of land use, and it is suitable for creating large-scale soil maps by defining soil series for use as mapping units. This classification system is also easily translated into international soil classification systems such as the World Reference Base for Soil Resources 2006 (WRB2006; IUSS Working Group WRB 2006) and the Soil Taxonomy 2010 (Soil Survey Staff 2010) (Obara et al. 2015).

From this background, we delineated a new 1:200,000 national soil map and 1:50,000 cultivated soil map in Japan based on CSCJ and WRB2006. This paper presents an overview of the recent development of CSCJ and WRB2006 maps in Japan and illustrates their significance of usability for the international science community.

Creation of a national soil map of Japan based on the Comprehensive Soil Classification System of Japan – First Approximation

The 1:200,000 NLS soil map of Japan was delineated using different classification systems for cultivated land and for forested areas. Consequently, soils derived from volcanic ash were classified differently under the different land uses. Therefore, this soil map could not be used to evaluate the national inventory of soil organic carbon because the mapping units did not accurately reflect past volcanic ash fallout, which strongly influences soil organic carbon content (Imaya et al. 2010). Kanda et al. (2016a) created a 1:200,000 CSCJ soil map of

Hokkaido as a first step toward preparing a CSCJ national soil map, using a database of existing soil profile information (e.g., Okuda et al. 2007, Takahashi and Higashi 2013), and an additional soil survey in forested areas to reinterpret the NLS soil map of this region. Large areas of NLS Brown Forest soils distributed in the southern volcanically active part of Hokkaido were classified as Allophanic Andosols in the CSCJ soil map. However, in northern Hokkaido, large areas of Brown Forest soils were retained as Brown Forest soils but in some cases were classified as Non-allophanic Andosols. Following the preparation of the Hokkaido map, Kanda et al. (2016b) created a similar CSCJ soil map for the Hokuriku and Chubu regions. Although they have less volcanic activity than Hokkaido, these regions are suggested to have a wider distribution of Andosols than the NLS soil map indicates, because the soils contained more than 1,500 mg P₂O₅ 100 g⁻¹ of phosphate adsorption coefficient (this value is one of the criteria of Andosols in CSCJ) distributed within the Brown Forest soils area in the NLS soil map (Takahashi and Higashi 2013, Toyama prefecture 1976, 1977, 1978). Consistent with these studies, the area of Andosols (mainly Non-allophanic Andosols) increased from 5% of the region in the NLS soil map to 27% in the CSCJ soil map, whereas that of Brown Forest soils decreased from 63% (NLS) to 31% (CSCJ).

As has been pointed out, it was difficult to distinguish Andosols classified by USCJ within Brown Forest soils area in NLS soil map (Kanno et al. 2008) because of lack of data about phosphate adsorption capacity or acid oxalate soluble Fe and Al in forest soils (Imaya 2014). However, our reviewed studies above could distinguish using existing soil profile information from that in published papers and additional soil surveys in forested areas. Therefore, soil groups in Andosols were mainly divided into Allophanic Andosols and Non-allophanic Andosols in these regions. It was thought that Allophanic Andosols in the southern part of Hokkaido contained noncrystalline minerals such as allophane and imogolite generated from fresh volcanic ash after Holocene, while Non-allophanic Andosols were distributed in northern parts of Hokkaido, Chubu and Hokuriku regions where volcanic ash before Holocene was accumulated due to decrease of the above minerals and contamination of aeolian dust (Saigusa et al. 1992, Matsuyama et al. 1994, Fujita et al. 2007, Okuda et al. 2007).

Obara et al. (2016a) applied similar methods as Kanda et al. (2016a,b) to create the CSCJ National Soil Map of Japan at a scale of 1:200,000 (Fig. 1). In this map, Andosols are the dominant soil great group, followed by

Brown Forest soils, Lowland soils and Red-Yellow soils. The area of the Andosols increased from 16% in the NLS soil map to 31% in the CSCJ soil map, and that of the Red-Yellow soils increased from 3% to 10%. Conversely, the area of Brown Forest soils decreased from 53% in the NLS soil map to 30% in the CSCJ soil map. The areas of Andosols increased in the regions of Hokkaido, Kanto, and Hokuriku where many volcanoes were distributed relative to other regions because new criteria of Andosols such as the phosphate adsorption coefficient were introduced, while criteria of the Red-Yellow soils increased in the Kinki, Chugoku, and Shikoku regions because soil colors such as brown and yellow, which was one of the criteria in Red-Yellow soils, were clearly distinguished. On the other hand, the distribution area of Organic soils, Podzols and Lowland soils did not show a big difference between NLS and CSCJ soil maps.

Development of a 1:50,000 cultivated soil map of Japan based on the Comprehensive Soil Classification System of Japan - First Approximation

The 1:50,000 CSCJ cultivated soil map of Japan was created using soil profile data records from the Fundamental Soil Survey for Soil Fertility Conservation and digital soil maps combining 2nd CSCS (Japan Soil Association 2005, Takata et al. 2011) and 3rd CSCS cultivated soils map (Takahashi 2013).

Wakabayashi et al. (2014) reclassified 868 soil profiles of the Fundamental Soil Survey for Soil Fertility Conservation according to the CSCJ, and compared the reclassification results with the original soil groups of the 2nd CSCS in two areas (Tochigi and Gunma prefectures in the Kanto region, Aichi and Mie prefectures in the Tokai region). Half the profiles classified as Wet Andosols, Brown Forest soils, Gray Upland soils, and Yellow soils in the 2nd CSCS were not classified in the corresponding soil groups of the CSCJ because the definitions of these soils had changed between the two classification systems. In the CSCJ, the soil groups and their diagnostic horizons and characteristics were clearly defined using analytical values and morphological properties similar to those used in the WRB2006. Wakabayashi et al. (2014) created CSCJ cultivated soil maps for above areas and found that volcanic ash soils in the Kanto region, which were described only as Andosols in the original 2nd CSCS cultivated soil map, were divided between Andosols (Vitric Andosols, Allophanic Andosols) and Volcanogenous Regosols in the CSCJ cultivated soil map. In addition, the Yellow soils group in the original 2nd CSCS cultivated soil map was eliminated in the CSCJ cultivated soil map and was replaced with several new soil groups, including Brown Forest soils,

Pseudo-gley soils, and Argic Red-Yellow soils (for examples, see the results for Aichi prefecture in Fig. 2A).

Kanda et al. (2017) created the CSCJ cultivated soil map for the remaining regions of Japan using the same methods as Wakabayashi et al. (2014) and estimated the occupancy rate of each soil great group of the CSCJ for the whole cultivated area of Japan. The largest area of distribution was the Lowland soils (47%), followed by Andosols (29%), which totaled 76% of the total cultivated area in Japan.

In the Lowland soils great group of the CSCJ cultivated soil map, the Gray Lowland soils group occupied the largest area. However, in the 2nd CSCS cultivated soil map, the Gley Lowland soils group was the largest. Unlike the 2nd CSCS, the 3rd CSCS and the CSCJ contained the Lowland Paddy soils group and Regosolic Lowland soils group in the Lowland soils great group, and the Gley Lowland soils group in the 2nd CSCS was divided into following three soil groups respectively exhibiting groundwater aquic feature (Gley Lowland

soils), irrigation water aquic feature (Lowland Paddy soils), and neither feature (Regosolic Lowland soils) in the CSCJ. By these changes, the soil profiles and the characteristics could be easily identified from the soil name.

In the Andosols great group of the CSCJ, both the Allophanic Andosols and Non-allophanic Andosols groups were new additions. In the CSCJ cultivated soil map, the Allophanic Andosols group comprised 59% of the area of the Andosols great group, whereas the Non-allophanic Andosols group occupied only 6%. Identifying the area of the Non-allophanic Andosols group is useful for horticultural management, because it has a very different acid reaction from the Allophanic Andosols group (Fig. 2B).

Creation of soil map of Japan based on the World Reference Base for Soil Resources 2006

Obara et al. (2016b) created a 1:200,000 WRB2006 national soil maps of Japan by translating the mapping

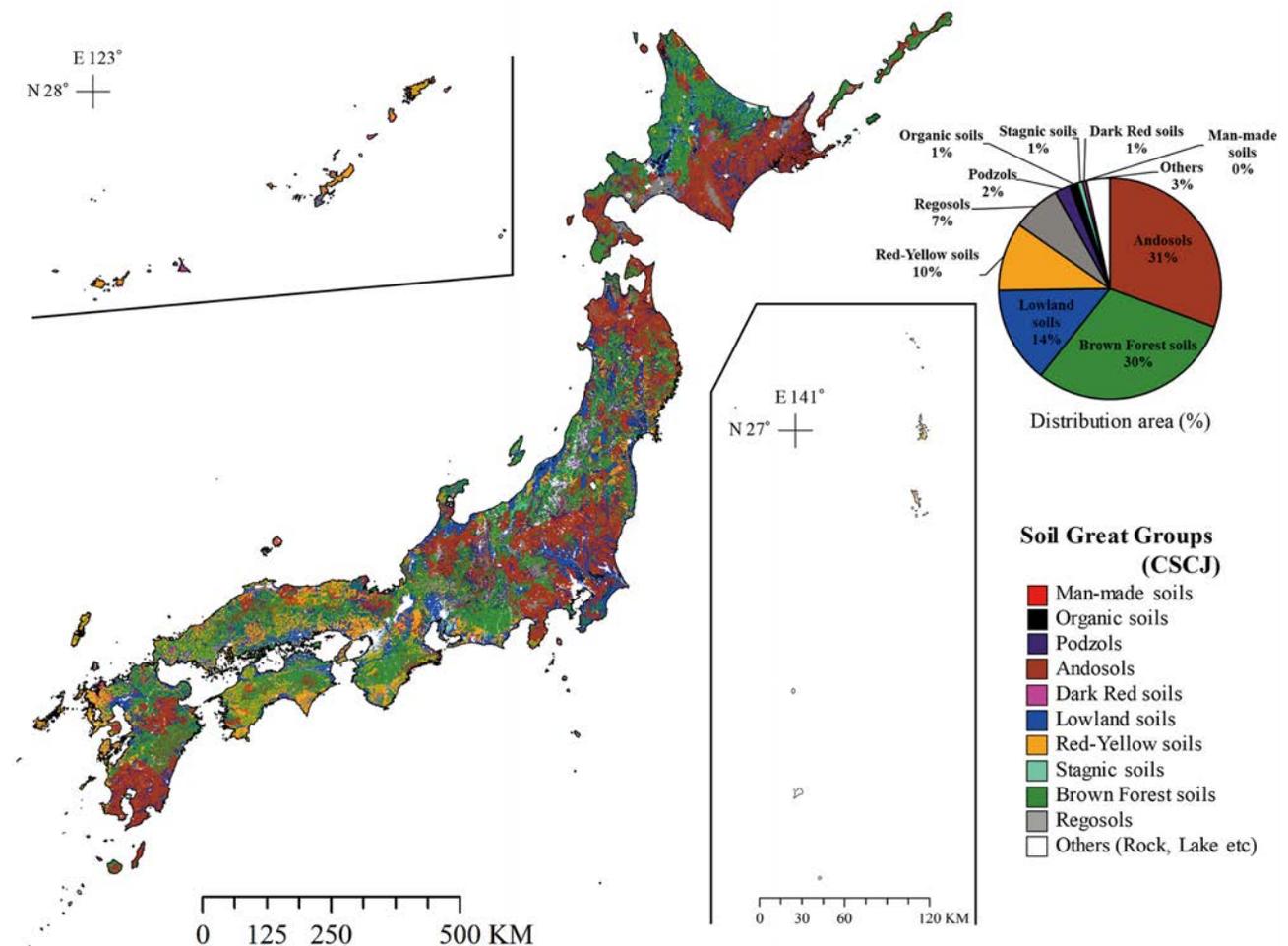


Fig. 1. The 1:200,000 soil map of Japan based on the Comprehensive Soil Classification System of Japan – First Approximation (CSCJ).

(The color of each Soil Great Group in this soil map was modified from Obara et al. (2016a).)

units of their CSCJ national soil map using a list of correlations between the two classification systems (Obara et al. 2011). The soil groups of the CSCJ are for the most part easily translatable into those of international soil classification systems such as the WRB2006 and Soil Taxonomy 2010. However, some soil groups and subgroups in the CSCJ do not correlate with a single soil group of the WRB2006 because of differences in definition. For example, Argic Dark Red soils and Argic Red-Yellow soils of the CSCJ correlate with several reference soil groups (Alisols, Acrisols, Luvisols, and Lixisols) of the WRB2006 because the CSCJ definitions do not refer to the activity of clay minerals and base saturation contained in WRB2006. In these cases, the reference soil groups of the WRB2006 were determined from soil profile data collected by the Fundamental Soil Survey for Soil Fertility Conservation. The exercise clearly demonstrated that soils with low-activity clay were dominant in western Kyushu and in Aichi and

Shizuoka prefectures, whereas soils with high-activity clay were dominant in other regions. Thus, Argic Dark Red soils and Argic Red-Yellow soils of the CSCJ were translated to Acrisols in western Kyushu, Aichi, and Shizuoka prefectures and to Alisols in all other regions.

Cambisols were the most abundant reference soil group in the WRB2006 national soil map of Japan, followed by Andosols and Fluvisols (Fig. 3). At 38% of the area, the distribution of Cambisols in the WRB2006 national soil map was greater than that of Brown Forest soils in the CSCJ national soil map (30%), primarily because Cambic Red-Yellow soils of the CSCJ national soil map, which are distributed mainly in the Kinki, Chugoku, and Shikoku regions, were correlated with Cambisols.

Recently, Hengl et al. (2017) created SoilGrid250m, a digital world soil map that can display soil class distribution for either WRB2006 or Soil Taxonomy systems. This soil map can be downloaded from the

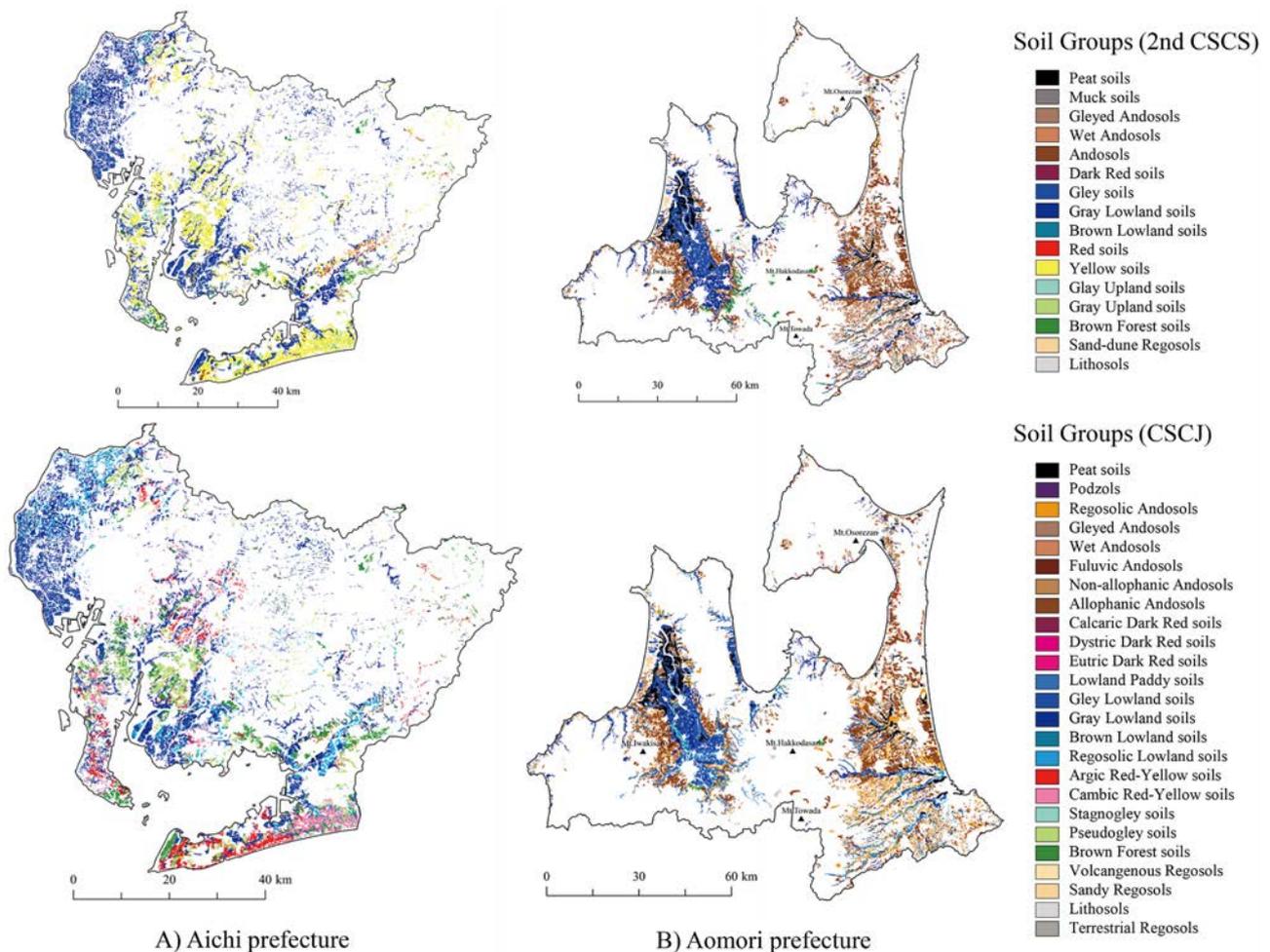


Fig. 2. The 1:50,000 cultivated soil maps of (A) Aichi and (B) Aomori prefectures according to the Classification System for Cultivated Soils revised 2nd Approximation (2nd CSCS) and the Comprehensive Soil Classification System of Japan – First Approximation (CSCJ).

(The color of each Soil Group in these soil maps were modified from Wakabayashi et al. (2014) and Kanda et al. (2017).)

website of the International Soil Reference and Information Center (https://soilgrids.org/#/?layer=geonode:taxnwrp_250m). According to this map described by WRB2006, Podzols are the dominant reference soil group in northern Japan and Cambisols are widely distributed from central to southern Japan, which is in some disagreement with the CSCJ national soil map. The CSCJ national soil map is based on data collected from many soil profiles over a long period of time in contrast with the number of profile in Japan (about 40 profiles) used in SoilGrid250m, and therefore represents a more accurate distribution of soil groups than the SoilGrid250m.

Conclusion

The CSCJ, the latest soil classification system in Japan, has been successfully applied to the large-scale cultivated soil map (1:50,000) and easily translated to the major international classification system, the WRB. The

new soil maps based on the CSCJ can be applied not only to the management of agricultural land, but also to environmental analyses at national and regional scales. Moreover, when translated to the WRB2006, the 1:200,000 CSCJ national soil map can contribute to the global soil information systems developed by the GSP. To support the continued development of the national soil maps, the historical data such as the Fundamental Soil Survey for Soil Fertility Conservation and the National Land Survey should be preserved and extended, and a national database should be established for the development of digital soil maps. Presently, these CSCJ soil maps have been released as the Japan soil inventory on the website of the Institute for Agro-Environmental Sciences, NARO (<http://soil-inventory.dc.affrc.go.jp/>), and the data of CSCJ soil maps has been also opened. We hope that CSCJ and new soil maps will become a common classification and that soil maps in Japan will be used by many people.

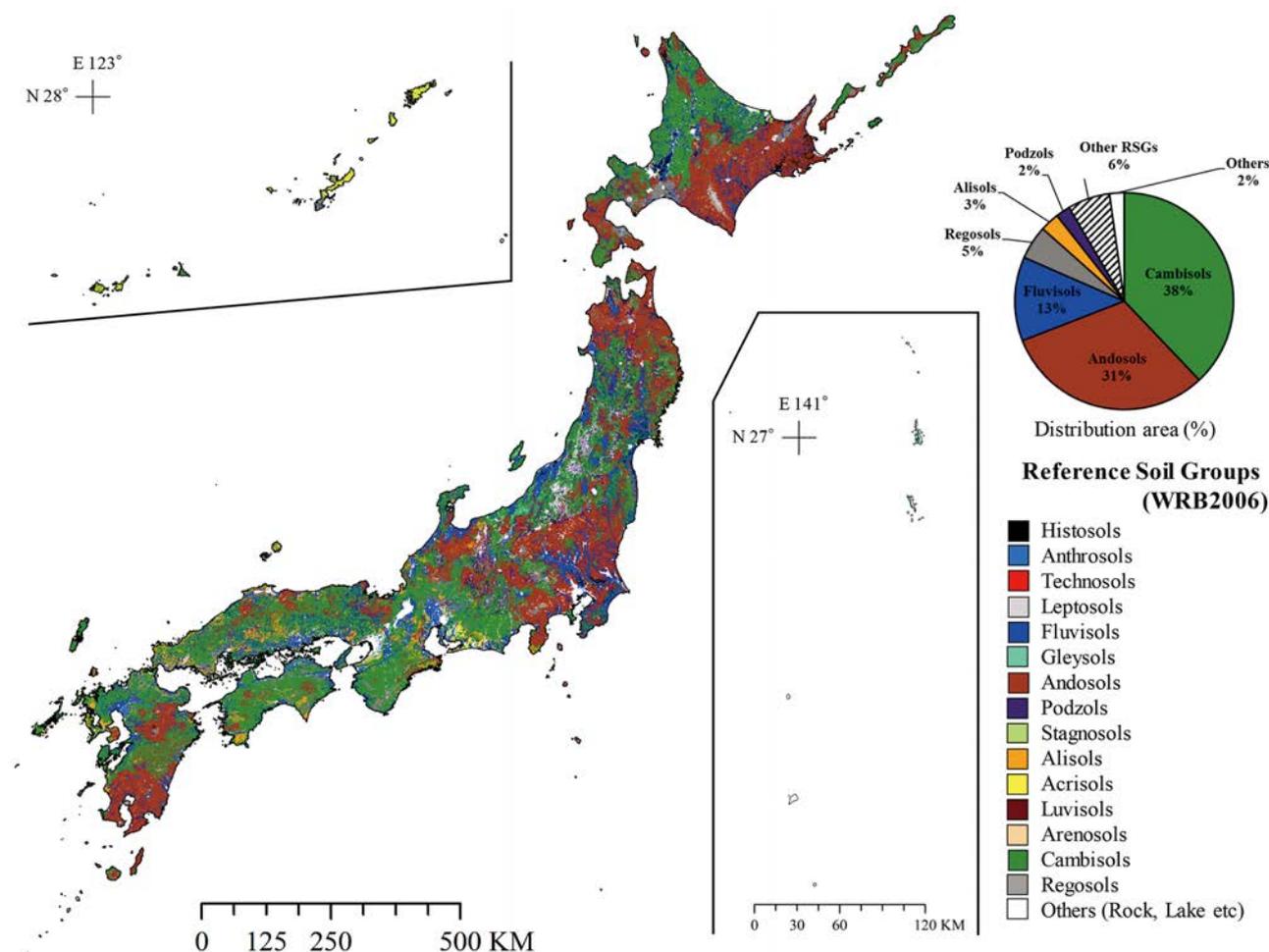


Fig. 3. The 1:200,000 soil map of Japan with mapping units based on the reference soil groups of the World Reference Base for Soil Resources 2006 (WRB2006) translated from a map based on the Comprehensive Soil Classification System of Japan – First Approximation.

(The color of each Reference Soil Group in this soil map was modified from Obara et al. (2016b).)

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