Possible toxicity of aluminium-humus complexes in Andosols

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Abstract
The nature and origin of the aluminum (Al) toxicity of allophanic Andosols is still unclear. We cultivated Al-sensitive plants and an Al-tolerant plant using Andosols having various properties. Burdock (*Arctium lappa*) and barley (*Hordeum vulgare*) were used as Al-sensitive plants and buckwheat (*Fagopyrum esclentum*) as an Al-tolerant plant. We measured the root lengths of the burdock and barley after a 4-day culture, and determined the Al concentrations of buckwheat plants after a month long culture. Typical non-allophanic soils showed the high toxicity of Al to roots of burdock and barley. Although Al toxicity was not observed in the typical allophanic soils in the Al-sensitive plants, acidic allophanic soils did show the toxicity as observed in the non-allophanic soils. Reflecting the toxicity (bioavailability) of these soils, the Al concentrations in buckwheat plants grown in the non-allophanic soils were much higher (2.6-4.3 mg/kg) than those in the typical allophanic soils (0.4-1.4 mg/kg). However, those concentrations of buckwheat in the acidified allophanic soils were comparable (2.7-4.0 mg/kg) to those in the non-allophanic soils. These allophanic Andosols contained a few 2:1 type minerals, therefore it is assumed that the Al^{3+} adsorbed into the permanently charged sites of the minerals is not abundant. Therefore, we concluded that Al-humus complexes play important roles in Al toxicity (availability) in the acidified allophanic Andosols as well as non-allophanic Andosols.

Key Words
Andisols, Kurobokusoils.

Introduction
Non-allophanic Andosols often show Al toxicity in Al-sensitive plant roots. The origin of the toxic Al has been considered to be primarily Al^{3+} adsorbed into the permanently charged sites of 2:1 type minerals (Saigusa *et al*. 1980; Shoji *et al*. 1993; Dahlgren *et al*. 2004). However, it was suggested that Al-humus complexes are also one of the pools of toxic Al (Takahashi *et al*. 1995, 2003, 2007; Ito *et al*. 2009). In contrast, typical allophanic Andosols rarely show Al toxicity to plant roots although allophanic soils also contain Al-humus complexes. With strong acidification, allophanic Andosols then come to possess toxic Al which causes injury plant roots (Takahashi *et al*. 2008). The origin of the toxic Al in the allophanic Andosols is still unclear. The aim of this study is to clarify the origin of toxic (bioavailable) Al in Andosols using the cultivation of Al-sensitive plants and an Al-tolerant plant.

Methods
Soil samples
Nine A horizon soil samples were used in this study (Table 1): two typical non-allophanic soils (Kawatabi 08 and Kawatabi 07), their limed soils, two typical allophanic soils (Morioka and Tsukuba), and three acidic allophanic soils (Utsunomiya, Yunodai and Tsutanuma). In addition, commercial pumice (Kanuma pumice) was used for comparison.

Table 1. Properties of soil samples

	$pH(H_2O)$	KCl-Al $cmol_c/kg$	Si_o g/kg	Al_p g/kg	Al_p/Al_o
Kawatabi 08	4.7	4.63	1.8	16.4	0.82
Kawatabi 07	4.4	5.95	1.8	16.2	0.80
Utsunomiya	4.6	4.62	16.3	11.8	0.26
Yunodai	5.3	0.72	9.9	9.5	0.31
Tsutanuma	5.4	0.06	16.4	6.0	0.15
Morioka	5.7	0.19	15.4	7.5	0.19
Tsukuba	7.0	0.07	20.7	3.2	0.08
Kanuma pumice	5.8	0.13	49.8	2.9	0.04

KCl-Al: 1M KCl extractable Al Al_o, Si_o: acid-oxalate-extractable Al and Si
Al_p: pyrophosphate-extractable Al

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Al-toxicity to Al-sensitive plants

We cultivated the burdock and barley in the soil samples (50 mL beakers). The seedlings were cultured at 25 ^{o}C. After 4-days, the plants were harvested and the length of the roots was measured (total length of the fibrous root system for barley and maximum length of the main root for burdock).

Al-availability to an Al-tolerant plant

Buckwheat is highly resistant to Al stress and known to be an Al-accumulator. Five seedlings were grown in soil samples (2 L pots) in a greenhouse kept at 25^{o}C with an appropriate water supply. After a growth period of a month, the plants were harvested and the Al concentrations of the shoots were determined.

Results

The typical non-allophanic soils (Kawatabi 08 and Kawatabi 07) showed the high toxicity of the Al to roots of burdock (Figure 1) and barley (Figure 2). The toxicity was mitigated in the limed soils (Kawatabi 08 (lime) and Kawatabi 07 (lime)). Although the Al toxicity in the Al-sensitive plant was not observed in the typical allophanic soils (Morioka and Tsukuba), the acidic allophanic soils (Utsunomiya, Yunodai and Tsutanuma) did show the toxicity as observed in the non-allophanic soils.

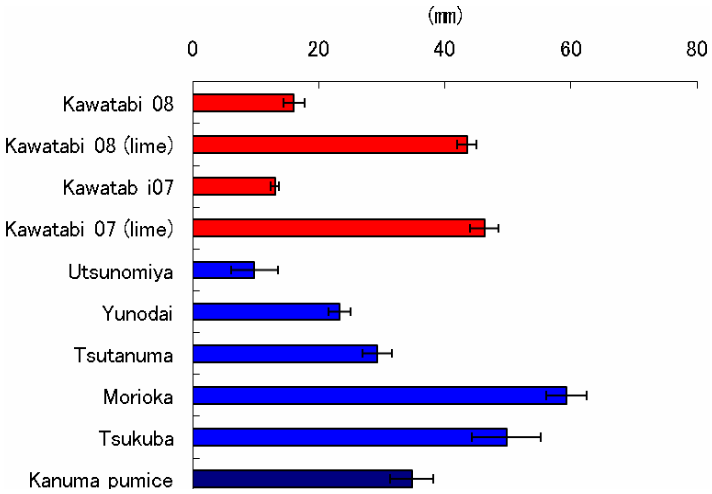

Figure 1. Length of main root of burdock

Reflecting the toxicity (bioavailability) of these soils, the Al concentration in buckwheat plants grown in the non-allophanic soils was much higher (2.6-4.3 mg/kg) than those in the typical allophanic soils (0.4-1.4 mg/kg) (Figure 3). However, the concentrations of buckwheat in the acidic allophanic soils were comparable (2.7-4.0 mg/kg) to those in the non-allophanic soils.

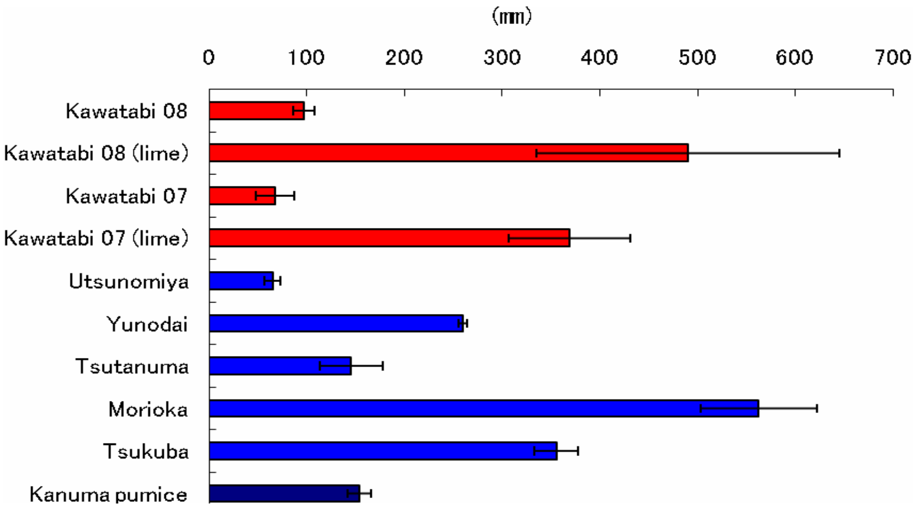

Figure 2. Total length of fibrous roots of barley

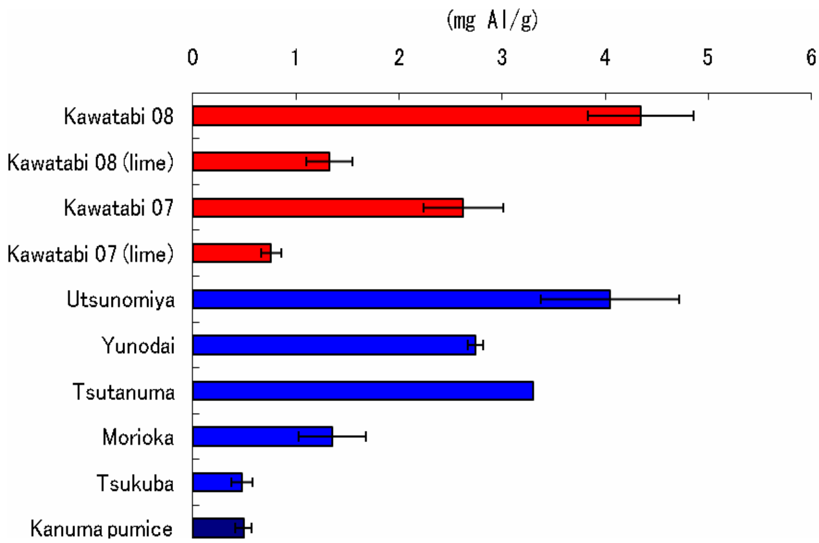

Figure 3. Al concentration in shoot of buckwheat

Figure 4 shows the relationships between the Al concentrations of buckwheat and the root length of burdock or barley. As expected, significant negative correlations were observed between the Al concentrations and the root lengths. Thus, the Al concentrations of buckwheat reflect the strength of the Al toxicity of soils to Al-sensitive plants.

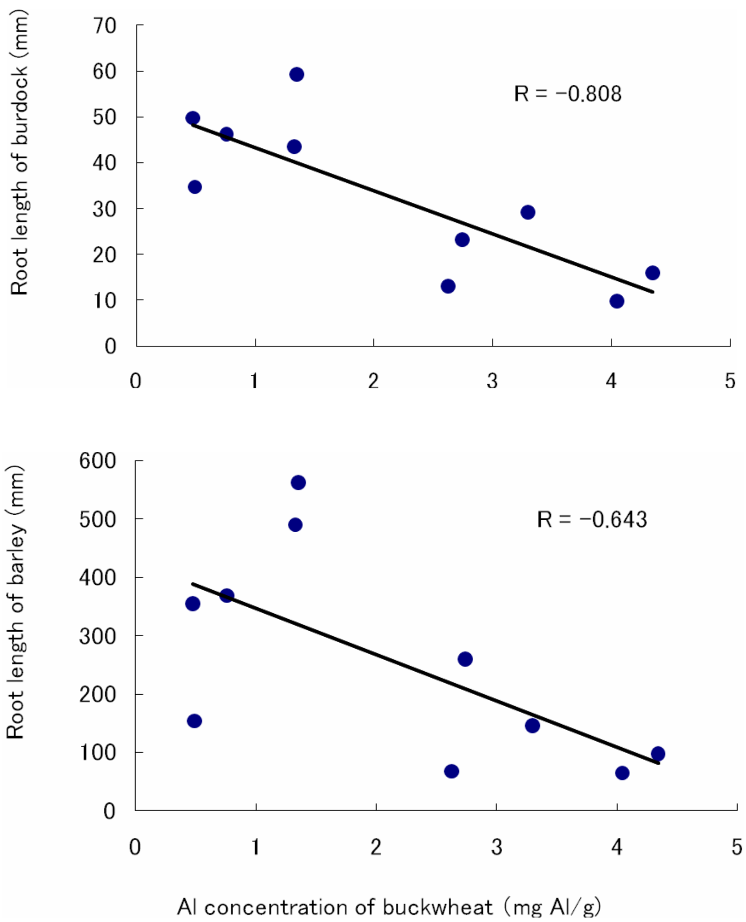

Figure 4. The relationship between Al concentrations of burdock and root lengths of burdock or barley

The Tsukuba and Morioka soils exhibited the typical properties of allophanic Andosols, such as high soil pH values, low concentrations of Al-humus complexes (low Al_p values) and low Al_p/Al_o ratios (Table 1). In contrast, the Utsunomiya and Yunodai soils possessed lower soil pH values, higher Al_p values and higher

Al_p/Al_o ratios. These properties are closer to those of non-allophanic Andosols. These allophanic Andosols contain a trace of 2:1 type minerals, so it is assumed that the Al^{3+} adsorbed into the permanently charged sites of the minerals is not abundant. Yagasaki *et al*. (2006) and Takahashi *et al*. (2008) revealed that, by acidification of the allophanic Andosols, the solubility of the soils can be controlled by the Al-humus complexes. Therefore, it is likely that the Al-humus complexes play important roles in the Al toxicity (bioavailability) in allophanic Andosols as well as non-allophanic Andosols.

Conclusion

The allophanic Andosols having lower soil pH values also showed Al toxicity (availability) as well as non-allophanic Andosols. We considered that the Al-humus complexes are closely related to the Al-toxicity in both the allophanic and non-allophanic Andosols.

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