シカクマメの沖縄各種土壌での生育およびリン栄養

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Growth of Winged Bean in Three Soil Types in Okinawa and the Effect of Phosphorus Nutrition

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Abstract

Acidic soil (red soil: RS), neutral soil (dark red soil: DRS), and alkaline soil (gray soil: GS) are main soils in Okinawa islands. We examined the growth and yield of winged bean (*Psophocarpus tetragonolobus*) cultivated in these soils in the field in 2007 and 2008. In RS, the contents of total phosphorus (P), Ca-bound P (available P), and Al-bounded P (unavailable) were lowest. Growth and yield of winged bean were significantly lower in RS than in DRS or GS. We also grew winged bean and velvet bean (*Mucuna pruriens*) in pots with RS with or without liming and P application. The growth of both species was promoted by P application but not by liming. Without P application, the growth of winged bean was lower than that of velvet bean. Tolerance of these species to low P was investigated in akadama soil, in which P was mainly bound to Al; the phosphate absorption coefficient of this soil was 23.9 g kg^{-1}. P-deficient (DP) and P-sufficient (SP) conditions were achieved by adding P at rates of 1% and 10% of the phosphate absorption coefficient, respectively. Growth and N-fixing activity of winged bean were significantly lower than those of velvet bean. We conclude that the decrease of winged bean growth and yield in RS is caused by P deficiency rather than its sensitivity to soil acidity.

Introduction

Winged bean (*Psophocarpus tetragonolobus*) is cultivated mainly in Southeast Asia as a vegetable crop (its young pods are used), and is a minor crop in Okinawa. Winged bean has the potential to be used for other purposes. We have reported that, as a cover crop, winged bean decreases soil erosion and controls weeds during the typhoon season, similar to velvet bean (*Mucuna pruriens*), which is widely used as a cover crop[1)]. Winged bean may also be used as green manure because the uptake of various nutrients by winged bean is larger than that by velvet bean[2)].

However, only neutral soils have been used in previous studies and the effect of acidic soils, which are widely distributed in tropical and subtropical regions, remains unknown. In this study, we investigated the growth and nutrient uptake of winged bean cultivated in acidic, neutral, and alkaline soil, and compared the tolerance of winged bean and velvet bean to low phosphorus.

Materials and Methods

1. Field performance of winged bean on three typical soils of Okinawa (Experiment 1)

The study was conducted at the Tropical Agriculture Research Front of the Japan International Research Center for Agricultural Sciences, Ishigaki, Okinawa, Japan (24.38N, 129.19E). Three different soils (red, dark red, and gray) in plots of 2 m × 2.4 m at

0.5 m depth were used. The chemical properties of the three soils are shown in Table 1. Winged bean (*Psophocarpus tetragonolobus* (L.) D.C. cv. Urizun) was sown on 6 April 2007 and on 12 May 2008, with five seeds per hill and 9 hills per plot (hill interval, 0.6 m × 0.4 m). No fertilizer was applied. Seedlings were thinned (2 plants per hill) 4 wk after sowing. Aboveground parts were harvested on 5 November 2007 and 27 October 2008 by sampling all plants within randomly placed quadrats (0.5 m × 0.5 m). The aboveground parts were separated into leaflets and stems + petioles, dried, and weighed. Fixed carbon and uptake of nitrogen and phosphorus by leaflets and stems + petioles were determined as described in subsection 4. Grains were harvested and weighed in February 2007 and 2008. Each treatment had three replicates.

2. Effects of liming and applying phosphorus on growth of winged bean and velvet bean in red soil (Experiment 2)

Red soil (15 kg) was mixed with 1 g each of N (as urea) and K_2O (as potassium sulfate) with or without addition of 40 g $CaCO_3$ and 1 g P_2O_5 (as superphosphate) and used to fill 1/2000 a pots. Chemical properties of used red soil are shown in Table 2. Five seeds of winged bean and velvet bean (*Mucuna pruriens* (L.) D.C.

Table 1. Soil chemical properties

	Red soil		Dark red soil		Gray soil	
	2007	2008	2007	2008	2007	2008
pH	5.5	5.5	6.4	6.4	8.1	7.8
EC ($\times 10^{-3}$S m^{-1})	4.0	3.0	4.2	2.7	13.5	12.1
Total Carbon ($\times 10^{-3}$ kg kg^{-1})	10.7	10.6	11.1	10.8	26.1	30.9
Total Nitrogen ($\times 10^{-3}$ kg kg^{-1})	1.3	1.2	1.5	1.5	0.9	1.2
C/N	8.2	9.2	7.2	7.3	29.9	26.6
Inorganic N ($\times 10^{-6}$ kg kg^{-1})	14.8	2.9	19.1	7.1	24.3	13.3
Total Phosphorus ($\times 10^{-3}$ kg kg^{-1})	0.2	0.2	0.8	0.8	0.3	0.3
Inorganic Phosphorus						
Ca bounded P ($\times 10^{-6}$ kg kg^{-1})	nd	nd	0.9	3.7	84.2	84.2
Al bounded P ($\times 10^{-6}$ kg kg^{-1})	9.0	4.9	49.9	61.1	55.7	48.0
Fe bounded P ($\times 10^{-6}$ kg kg^{-1})	50.6	45.1	174.1	177.7	25.9	17.6
Phosphate Absorption Coefficient ($\times 10^{-3}$ kg kg^{-1})	7.5	6.9	9.6	8.8	8.3	9.8
Exchangeable Cation						
K ($\times 10^{-3}$ mol_c kg^{-1})	13.2	un	9.8	un	22.3	un
Ca($\times 10^{-3}$ mol_c kg^{-1})	30.7	un	82.3	un	187.7	un
Mg ($\times 10^{-3}$ mol_c kg^{-1})	12.4	un	18.2	un	10.4	un
Na ($\times 10^{-3}$ mol_c kg^{-1})	1.8	un	3.0	un	1.6	un

un : un known

var. *utilis* cv. Hashou) were sown on 8 July 2008. Seedlings were thinned (2 plants per pot) 2 wk after sowing. N-fixing activity was measured by the acetylene reduction method using gas chromatography (GS-2; Sensortec, Tokyo, Japan)[3]. On 24 September 2008, leaflets, stems + petioles, roots, and nodules were dried at 70°C for 3 d and weighed. Each treatment had three replicates.

Table 2. Soil chemical properties (Experiment 2 and 3)

	Red soil	Akadama soil
pH	4.9	6.1
EC (10^{-3}S m^{-1})	9.8	6.9
Total Carbon ($\times 10^{-3}$ kg kg^{-1})	1.3	9.6
Total Nitrogen ($\times 10^{-3}$ kg kg^{-1})	0.3	0.9
C/N	5.1	11.2
Inorganic N ($\times 10^{-6}$ kg kg^{-1})	3.1	2.6
Total Phosphate ($\times 10^{-3}$ kg kg^{-1})	0.14	4.10
Inorganic Phosphate ($\times 10^{-6}$ kg kg^{-1})		
Ca bounded P ($\times 10^{-6}$ kg kg^{-1})	nd	nd
Al bounded P ($\times 10^{-6}$ kg kg^{-1})	nd	248.3
Fe bounded P ($\times 10^{-6}$ kg kg^{-1})	nd	nd
Phosphate Absorption Coefficient ($\times 10^{-3}$ kg kg^{-1})	4.1	23.9

3. Tolerance of winged bean and velvet bean to low phosphorus (Experiment 3)

Akadama soil (6 kg) was mixed with 1 g each of N (as urea) and K_2O (as potassium sulfate). Superphosphate was added at rates of 1% (P-limiting condition; DP) or 10% (P-non-limiting condition; SP) of the P_2O_5 absorption coefficient of akadama soil. Chemical properties of used akadama soil are shown in Table 2. Winged bean and velvet bean seeds (five each) were sown on 24 June 2008. Seedlings were thinned (2 plants per pot) 2 wk after sowing and cultivated until 1 September 2008. N-fixing activity was measured as in Experiment 2. Leaflets, stems + petioles, roots, and nodules dried at 70°C for 3 d and weighed. Each treatment had three replicates.

4. Plant analyses

Dried plant organs were ground to a powder and total C and N contents were determined using a CHN Corder (JM10; G-Science Laboratory Company, Tokyo, Japan). Total P was determined by calorimetry after combustion at 450°C for 1 h and dissolving the resulting ash in nitric acid diluted 1:30 (v:v) [4]. K, Ca, and Mg concentrations were determined by using an atomic absorption spectrophotometer (Z-2010; Hitachi, Tokyo, Japan) after Kjeldahl digestion with H_2SO_4 and H_2O_2.

5. Soil analyses

Soils were air-dried and passed through a 2-mm sieve. Soil pH was measured in 1:2.5 (w:v) soil:water slurries and electrical conductivity (EC) in 1:5 slurries. Total C and N contents were determined using JM10. The content of inorganic N was determined by steam distillation after extraction with 2 mol L^{-1} KCl. Total phosphate was determined by calorimetry after digestion with HNO_3 and $HClO_4$. The phosphate absorption coefficient was determined calorimetrically after absorption with 25 g L^{-1} $(NH_4)_2HPO_4$. Ca-bound phosphate (available phosphate), Al-bound phosphate, and Fe-bound phosphate were determined calorimetrically after extraction with 25 mL L^{-1} acetic acid, 1 mol L^{-1} ammonium fluoride, and 4 g L^{-1} sodium hydroxide. Exchangeable cations were determined using an atomic absorption spectrophotometer (Hitachi Z-2010) after extraction with 1 mol L^{-1} ammonium acetate.

6. Statistical analysis

The differences between the mean values were assessed by one-way analysis of variance. Multiple comparisons were carried out by Tukey HSD test ($p<0.05$) using SPSS statistics (v.22J).

Results

1. Field performance of winged bean on different soils (Experiment 1)

Chemical properties of red soil (RS; acid), dark red soil (DRS; neutral) and gray soil (GS; alkaline) are shown in Table 1.

The content of exchangeable calcium and Ca-bound P (available) was highest in GS and lowest in RS. Available P was undetectable in RS in both years. Biomass, fixed carbon, and uptake of nitrogen and phosphorus were lower in RS than in DRS and GS (Fig. 1). This difference was statistically significant in 2008.

The yield was significantly lower in RS than in DRS and GS in both years (Fig. 2). It was significantly lower in DRS than in GS in 2007, but almost no difference was detected in 2008.

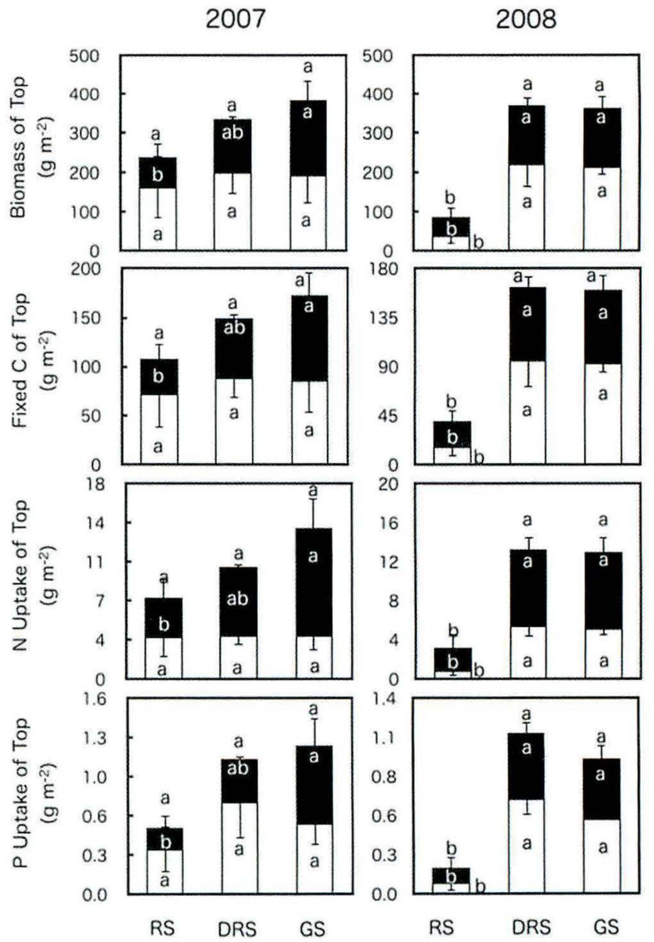

Fig. 1　Growth and mineral uptake of winged bean cultivated in deffrent Okinawan soils

■ leaf lets　□ stems + petiols

RS : red soil　DRS : dark red soil　GS : gray soil

a, b : statically significant difference (Tukey HDS p<0.05)

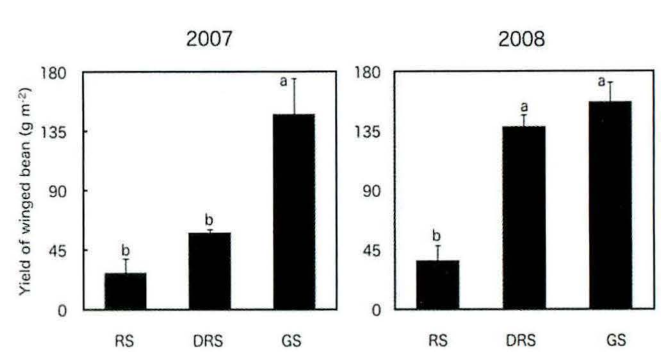

Fig. 2　Yield of winged bean cultivated in deffrent Okinawan soils

RS : red soil　DRS : dark red soil　GS : gray soil

a, b : statically significant difference (Tukey HDS p<0.05)

Temperature and precipitation near the experimental site[5] are shown in Fig. 3. Temperature changes were similar in both years. Monthly precipitation from August to November in 2007 was constant (250–300 mm); in September 2008, it was ~600 mm, but in the other months of 2008 it was lower than in 2007.

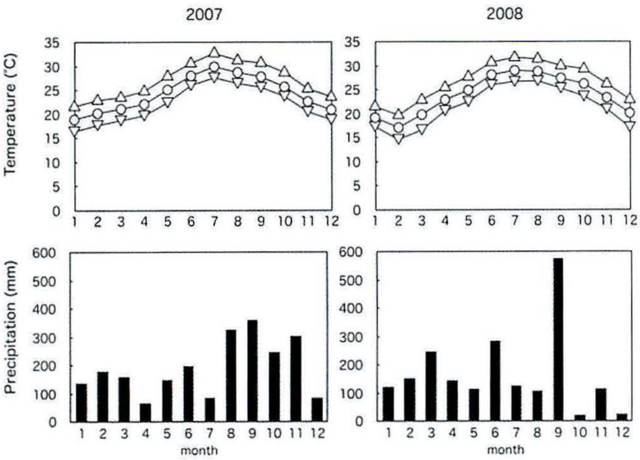

Fig. 3 Behavior of monthly temperature and precipitation of the nearest observation site (Maesato, Ishigaki island) in 2007and 2008

△ The average daily maximum temperature
○ The average daily mean temperature
▽ The average daily minimum temperature

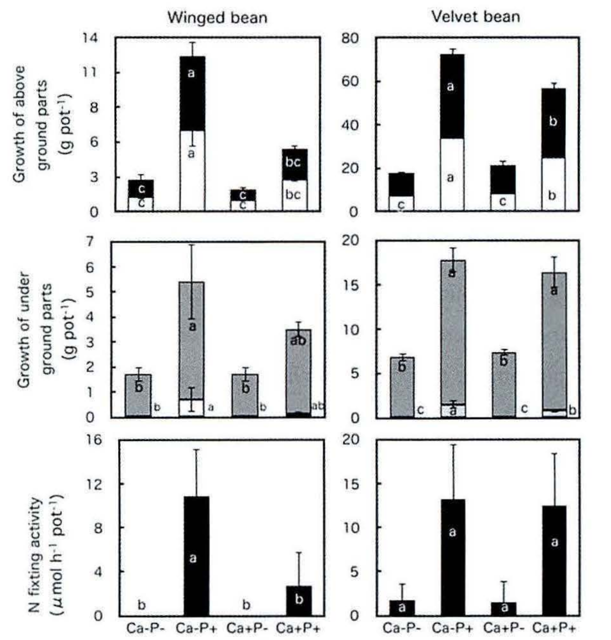

Fig. 4 Effects of liming and phosphate fertilizing on growth and N-fixing activity of winged bean and velvet bean cultivated in acidic red soils

■ leaf lets □ stems + petiols ▩ roots □ nodules

Ca+ : liming Ca- : no-liming P+ : fertilizing P P- : no-fertilizing P

a, b, c : statically significant difference (Tukey HDS p<0.05)

2. Effects of liming and adding phosphorus on the growth of winged bean and velvet bean in red soil (Experiment 2)

Application of calcium did not increase growth and N_2-fixing activity in either species and even tended to reduce these parameters in winged bean (Ca+ in Fig. 4). Phosphorus application clearly increased growth and N_2-fixing activity in both species (P+ in Fig. 4); the effect was larger in the growth of aboveground parts and nodules than that of roots. The dry weight of aboveground parts without calcium or phosphorus (Ca–P–) was 2.6 g pot^{-1} for winged bean and 18.0 g pot^{-1} for velvet bean.

3. Tolerance of winged bean and velvet bean to low phosphorus (Experiment 3)

Growth of both species and N_2-fixing activity of winged bean were significantly lower under the P-limiting than under non-limiting condition (Fig. 5). The decrease in growth and N_2-fixing activity was more noticeable in winged bean than in velvet bean. Under the P-limiting condition, biomass of aboveground parts was 3.1 g pot^{-1} for winged bean and 42.2 g pot^{-1} for velvet bean.

Discussion

A previous study indicated that biomass production of winged bean is similar to that of velvet bean, which is widely cultivated as a cover crop, and seed yield of winged bean as a cover crop was expected to be about 200 g m^{-2} without fertilization in neutral or weakly acidic soil[1]. Winged bean is considered a valuable crop because its seeds are used as a raw material for cosmetics and for fermented food (miso) [6), 7)].

However, in this study, we found that biomass, nutrient uptake into aboveground parts, and seed yield of winged bean were much lower in red soil. This soil was strongly acidic and had a lower content of exchangeable Ca, Ca-bound phosphate (Ca-P) and Al-bound phosphate (Al-P) than the other two soils. We believe that the decrease of growth and yield in red soil was caused by phosphorus deficiency. In spite of the lower content of exchangeable Ca and Ca-P in dark red soil than in gray soil, the growth and yield of winged bean in both soils were similar. Dark red soil contained the highest concentration of Al-bound and Fe-bound phosphate (Fe-P), which are both unavailable to plants, and also had the highest content of total phosphate, which includes organic phosphate. Therefore, winged bean may be able to uptake Al-P and/or Fe-P from the soil.

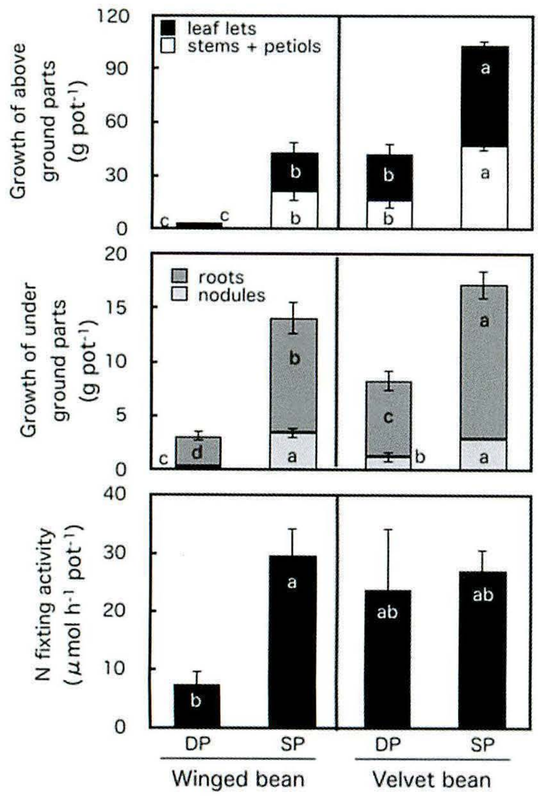

Fig. 5 Growth and N-fixing activity of winged bean and velvet bean cultivated in phosphate limiting and no-limiting condition

DP : limiting P condition SP : no-limiting P condition

a, b, c : statically significant difference (Tukey HDS $p<0.05$)

We also assessed the effects of liming and phosphate application on the growth of winged bean and velvet bean grown in pots in red soil, which had lower pH and total phosphate content than soil in experiment 1, and no detectable Ca-P, Al-P, and Fe-P. The growth and N-fixing activity of both species were decreased by liming treatment. Liming increases red soil hardness when soil is dry, which may have reduced root elongation in both species. However, we did not monitor the status of soil water in this experiment, and further studies are needed to assess the effect of liming on soil hardness and root elongation.

The use of red soil with extremely low phosphorus content in experiment 2 made the effect of phosphorus application on the growth and N fixation of both legumes very clear; growth and N-fixing activity of winged bean declined more strongly than those of velvet bean.

To compare tolerance to low phosphorus, we cultivated winged bean and velvet bean in akadama soil (a volcanic ash soil; Exp. 3), which is weakly acidic and suitable for testing tolerance to low phosphorus[8]. The growth of winged bean under the phosphorus-limiting condition was lower than that of velvet bean. Moreover, N-fixing activity of winged bean strongly declined under phosphorus-limiting conditions. From these results, we concluded that tolerance to low phosphorus is weaker in winged bean than in velvet bean, whereas that of velvet bean is similar under phosphorus-limiting and non-limiting condition.

We assume that the reduction of growth and yield of winged bean cultivated in acidic red soil was induced by phosphorus deficiency; therefore, cultivation of winged bean seems to be advantageous in neutral dark red soil or alkaline gray soil. However, acidic red soil is widely distributed in tropical and subtropical regions, including Okinawa. A large amount of phosphorus fertilizer is effective for increasing the yield of winged bean in acidic red soil, although phosphorus fertilizer is expensive and may become even more expensive in the future. The use of unavailable inorganic phosphorus such as Fe-P and Al-P by winged bean needs to be further investigated. Additionally, the effects of mycorrhizal fungi on the growth of winged bean in low-phosphorus soil need to be studied. Further investigations are needed to increase the growth and grain yield of winged bean.

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*Japanese with English abstract

和文要約

沖縄に分布する酸性の赤色土、中性の暗赤色土、アルカリ性の灰色低地土の圃場で栽培したシカクマメ(*Psophocarpus tetragonolobus*)の生育量と収量を 2007 年と 2008 年の 2 年間調査した。全リンおよび Ca 型リン酸、Al 型リン酸の最も少ない赤色土でシカクマメ生育量と収量はたの土壌に比べて有意に低下した。赤色土に石灰施用とリン施肥の有無による処理区を設けて栽培したシカクマメとハッショウマメ(*Mucuna pruriens*)の生育量は石灰施用の有無にかかわらずリン施肥で低下し、低下度合はシカクマメで強く示された。リン酸を Al 型で固定する赤玉土にリン酸吸収係数の 1%と 10%のリン酸施肥をして準備したリン欠乏区とリン適量区でシカクマメとハッショウマメを栽培した結果、欠乏区における生育量と窒素固定活性はシカクマメで著しく低下した。これらのことから赤色土でのシカクマメの生育量と収量の低下は土壌酸性による影響よりもリン欠乏の可能性が明らかになった。