EFFECTS OF WATERLOGGING ON GROWTH AND YIELD OF YARD LONG BEAN (*Vigna sinensis* var. *sesquipedalis*)

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ABSTRACT

In order to analyse the effects of waterlogging on the growth and yield of yard long bean, one of the representative leguminous vegetables in tropical Asia, a series of experiments was carried out. Soils were sterilized before use to minimize the interaction between plant growth and soil microorganisms. Short-term waterlogging (4 days) at the vegetative stage retarded the growth during the treatment, but rapid recovery, especially in roots, was observed soon after the termination of the treatment. The yield had a tendency to be reduced. Both long-term (16 days) and continuous waterlogging (treatment continued up to harvest) restricted the growth until adventitious root formation. Thereafter the plants showed rapid recovery. Long-term waterlogging severely retarded the post-stress growth, while plants subjected to continuous waterlogging were able to maintain active growth. The yield was drastically reduced by long-term waterlogging, but little by the continuous treatment. The short-term waterlogging effect depended on the stage of growth and the genotypes. The factors which affect the plant response to waterlogging are discussed in relation to the activities of soil microorganisms. Several problems relating to breeding of tropical leguminous vegetables for waterlogging tolerance and cultural practices for preventing flooding damage are also considered.

Introduction

In tropical Asia, heavy rainfall in the rainy season frequently induces short-term flooding in vegetable fields. This phenomenon is accelerated by poor drainage system, uneven local topography and high groundwater level. Under these conditions, vegetables cultivated are damaged to various degrees, resulting in poor growth and low yield.

Yard long bean is widely cultivated for young pod consumption in East, Southeast and South Asia. Especially in tropical Asia, this crop is one of the most important vegetables cultivated all the year round. For the above-mentioned reasons, yard long bean plants are sometimes subjected to the detrimental effect of waterlogging. This problem is one of the major factors which restrict the productivity of this crop in such areas.

Although some information is available in other leguminous crops (Minchin and Summerfield, 1976 ; Wadman-Van and Van Andel, 1985 ; Wien *et al.*, 1979), detailed studies on the response of yard long bean plants to waterlogging have not been conducted so far. A series of experiments was designed to obtain fundamental information about this problem (Nawata, 1990 ; Nawata *et al.*, 1990).

Some of the plant responses caused by waterlogging are known to be mediated by the activities of microorganisms (Fitter and Hay, 1981). In these experiments, soil was sterilized by fumigation before use to minimize the interaction between plants and soil microorganisms and evaluate the direct influence of soil anaerobiosis on plants.

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Effect of waterlogging duration

Duration of soil submersion is one of the major factors which influence the plant response to waterlogging. It is generally considered that the longer the waterlogging period, the more adversely plants are affected. In order to clarify the effect of the length of the waterlogging period, the following experiment was carried out (Nawata *et al.*, 1990).

Yard long bean plants, cv. 'TKC-83' (local variety of Thailand) were sown in vermiculite on May 2nd in 1988. Ten days later they were transplanted in 24 cm diameter clay pots filled with a mixture of sand and organic manure at the ratio of 2 : 1. Plants were grown in a plastic greenhouse without control of the temperature. Proper amount of nutrient solution (half strength of 'Enshi' solution, Yamazaki, 1982) was supplied as needed.

Waterlogging treatment was applied by placing the pots into plastic buckets and filling the buckets with the nutrient solution. Appropriate number of plants was subjected to waterlogging for 4 days (short-term treatment), 16 days (long-term treatment) and all the remaining period until harvest (continuous treatment). The treatment began at 28 days after sowing when 2-3 trifoliate leaves were expanded.

At 0, 4, 16 and 28 days after the beginning of the treatment samples were taken and each sample was weighed after drying at 80°C for 4 days. Although the end-product of yard long bean is an immature pod, seed yield was measured, because it is much easier to measure this parameter than the pod yield and it was found that there was a high correlation between the effect of waterlogging on seed yield and that on pod yield (Nawata and Shigenaga, 1988). Several characteristics relating to yield were also determined.

Short-term waterlogging retarded the growth of both the above-ground parts and roots during the treatment, but rapid recovery, especially in roots, was observed soon

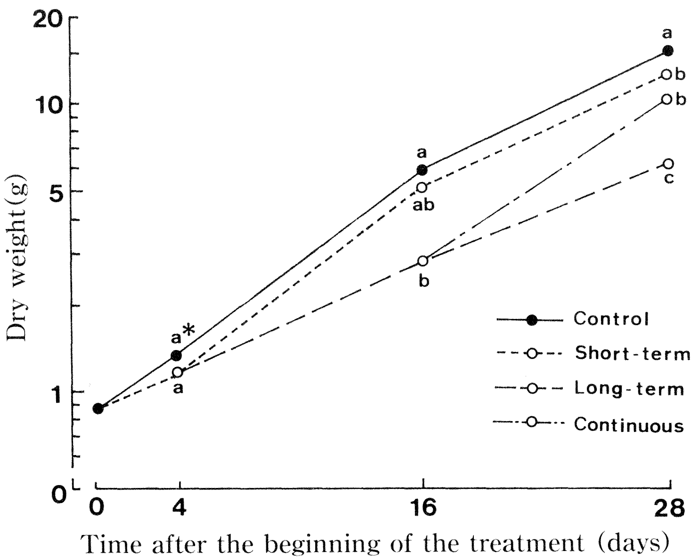

Fig. 1 Effect of waterlogging duration on dry weight of shoot in yard long bean
* Different letters indicate significant difference at p = 0.05.

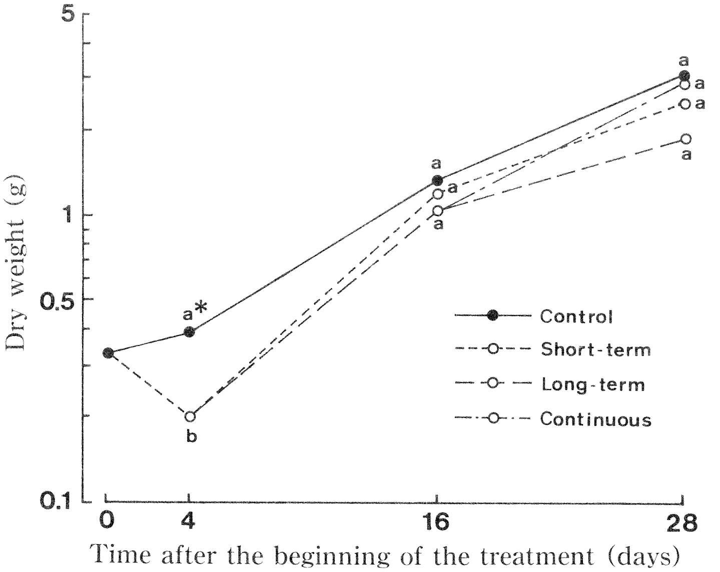

Fig. 2 **Effect of waterlogging duration on dry weight of root in yard long bean**

*Different letters indicate significant difference at $p=0.05$.

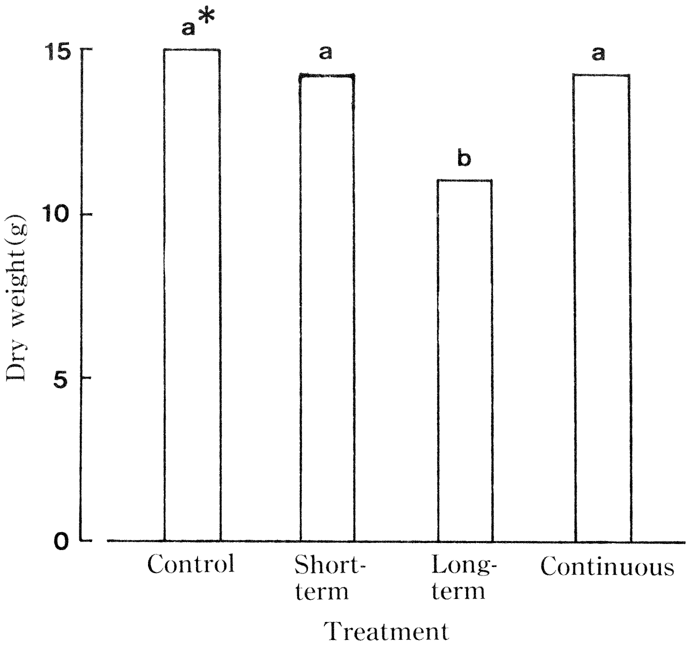

Fig. 3 **Effect of waterlogging duration on seed yield of yard long bean**

*Different letters indicate significant difference at $p=0.05$.

after the termination of the treatment (Fig. 1, Fig. 2). Seed yield was slightly reduced by this treatment without statistical significance (Fig. 3).

Long-term treatment restricted the growth of the above-ground parts until the 16th day after the beginning of the treatment (the day when the treatment was completed). Roots recovered from the damage which was observed after the first 4 days of the treatment. This recovery was mainly due to the formation of adventitious roots. Post-stress growth was restricted in both the above-ground parts and roots. Flowering was delayed significantly (Table 1), and the yield was drastically reduced by the treatment.

Both the above-ground parts and roots showed further recovery in the continuous treatment plot. Yield was not reduced significantly, although flowering was slightly delayed. Seed size was reduced by this treatment, but it was compensated by the increase of the number of seeds per pod.

The results obtained here indicate several interesting aspects. Firstly, yard long bean cv. 'TKC-83' was not only able to survive under the continuous waterlogging conditions but also the yield was comparable to that of the non-stressed control. This fact reveals that if indirect influences by soil microorganisms are eliminated and proper nutrients are supplied, yard long bean plants can adapt themselves to waterlogging conditions, presumably by the development of aerenchyma and abventitious roots.

Secondly, the long-term treatment in this experiment restricted the growth and yield severely as compared to the other 2 treatments. It was shown that once yard long bean plants became adapted to the waterlogging conditions, the discontinuation of the treatment resulted in adverse effects on the plants. Because most of the active adventitious roots are located near the water surface, they are exposed to air upon the removal of the stress and become useless for water and nutrient uptake. Thus if prolonged waterlogging is discontinued, plants are subjected to dual stress, that is the first stress caused by soil anaerobiosis and the second caused by the removal of the stress after the adaptation to the anaerobic conditions. Even if the waterlogging period is short, plants are subjected to this dual stress, but usually the adaptation of plants is not complete in this case and the damage caused by the second stress is not very severe.

Effect of the stage of growth and varietal differences

The stage of growth affects the plant response to short-term waterlogging. In many crops, the germination and flowering time are known to be the most sensitive stages to waterlogging (Krizek, 1982). It has also been reported that there are intraspecific differences in the plant response to waterlogging (Krizek, 1982). In this experiment, plants were subjected to short-term waterlogging at the vegetative stage (2-3 trifoliate leaves expanded) and at the flowering stage (first flower just opened) and the plant response was evaluated and compared using several varieties (Nawata, 1990).

Yard long bean plants, cv. 'TKC-83', 'I-2939-Wonosobo' (Indonesian variety),

Table 1 Effect of waterlogging duration on number of days to first flower and various characteristics relating to yield of yard long bean

Treatment	Number of days to first flower	Number of pods Main stem	Number of pods Lateral shoot	Number of seeds per pod	100-seed weight (g)	Pod set rate (%)
Control	56.8b*	9.1a	4.4ab	10.0ab	10.8a	46.8b
Short-term	57.0b	9.6a	3.9ab	9.9b	10.0b	50.2ab
Long-term	64.0a	8.3a	1.2b	11.1ab	9.9b	54.4ab
Continuous	59.6b	9.0a	4.8a	11.6a	8.4c	58.5a

* Different letters indicate significant difference at $p=0.05$.

'Akadane-Sanjaku' (Japanese variety) and 'Kurodane-Sanjaku' (Japanese variety) were sown on May 11th in 1988 and transplanted 10 days later. Cultural practices and the treatments were the same as those described previously. Appropriate number of plants was subjected to waterlogging for 4 days at the vegetative stage and the flowering stage. Seed yield and several characteristics relating to yield were determined.

Fig. 4 and Table 2 show the varietal differences in the effect of short-term waterlogging at the vegetative and the reproductive stage on seed yield and yield components. 'TKC-83' was little affected by the treatment at the vegetative stage, in contrast with the results of former experiments (Nawata and Shigenaga, 1988 ; Nawata *et al.*, 1990). In the unstressed control itself lateral shoot development was suppressed presumably due to the higher plant density and high temperature at the vegetative stage, which may account for the discrepancy with the previous results. Waterlogging at the flowering stage did not appreciably affect seed yield as in the previous experiment. The yield of 'I-2939-Wonosobo' was also little affected by the treatment at both stages. Waterlogging at the vegetative stage reduced the yield of 'Akadane-Sanjaku' significantly, which may be related to the decrease of the number of pods on the lateral shoots, while the treatment at the flowering stage exerted a limited influence. On the contrary, the yield of 'Kurodane-Sanjaku' was little affected by the treatment at the vegetative stage, and significantly reduced by that at the flowering stage, which is also considered to be associated with the decrease of the number of pods on the lateral shoots.

The current results indicated that the sensitivity of the plants to waterlogging differed depending on the growth stages and that the stage at which plants are most susceptible to the stress differed among varieties. It is also suggested that there are varietal differences in the extent to which short-term waterlogging may affect plants.

Discussion

It is well recognized that waterlogging of the soil causes a reduction of growth and

Table 2 Effect of short-term waterlogging at different stages on number of days to first flower and various characteristics relating to yield in several varieties of yard long bean

Varieties and treatment	Number of days to first flower	Number of pods Main stem	Lateral shoot	Number of seeds per pod	100-seed weight (g)	Pod set rate (%)
TKC-83						
Control	54.2a*	8.3ab	2.7a	10.2a	8.9a	45.7a
W. V.**	53.5a	7.5b	3.2a	10.7a	9.6a	49.5a
W. R.	52.0a	9.8a	1.9a	8.8a	9.0a	54.9a
I-2939-Wonosobo						
Control	61.0a	5.8a	7.7a	11.3a	11.6b	35.0a
W. V.	60.7a	4.8a	9.0a	11.0a	12.0ab	42.6a
W. R.	61.0a	4.5a	7.8a	11.3a	13.9a	39.9a
Akadane-Sanjaku						
Control	65.3a	7.0a	9.8a	9.7a	9.3a	57.6a
W. V.	64.8a	6.8a	5.5b	10.7a	9.4a	48.1a
W. R.	65.0a	5.8a	7.0a	11.4a	12.0a	59.5a
Kurodane-Sanjaku						
Control	62.8a	6.5a	10.5a	9.6a	10.6b	57.5a
W. V.	65.2a	6.7a	11.8a	9.7a	10.5b	64.9a
W. R.	64.7a	5.8a	5.4b	9.9a	12.3a	48.7a

* Different letters indicate significant difference at $p=0.05$.
** W. V. ; Waterlogged at the vegetative stage.
W. R. ; Waterlogged at the reproductive stage.

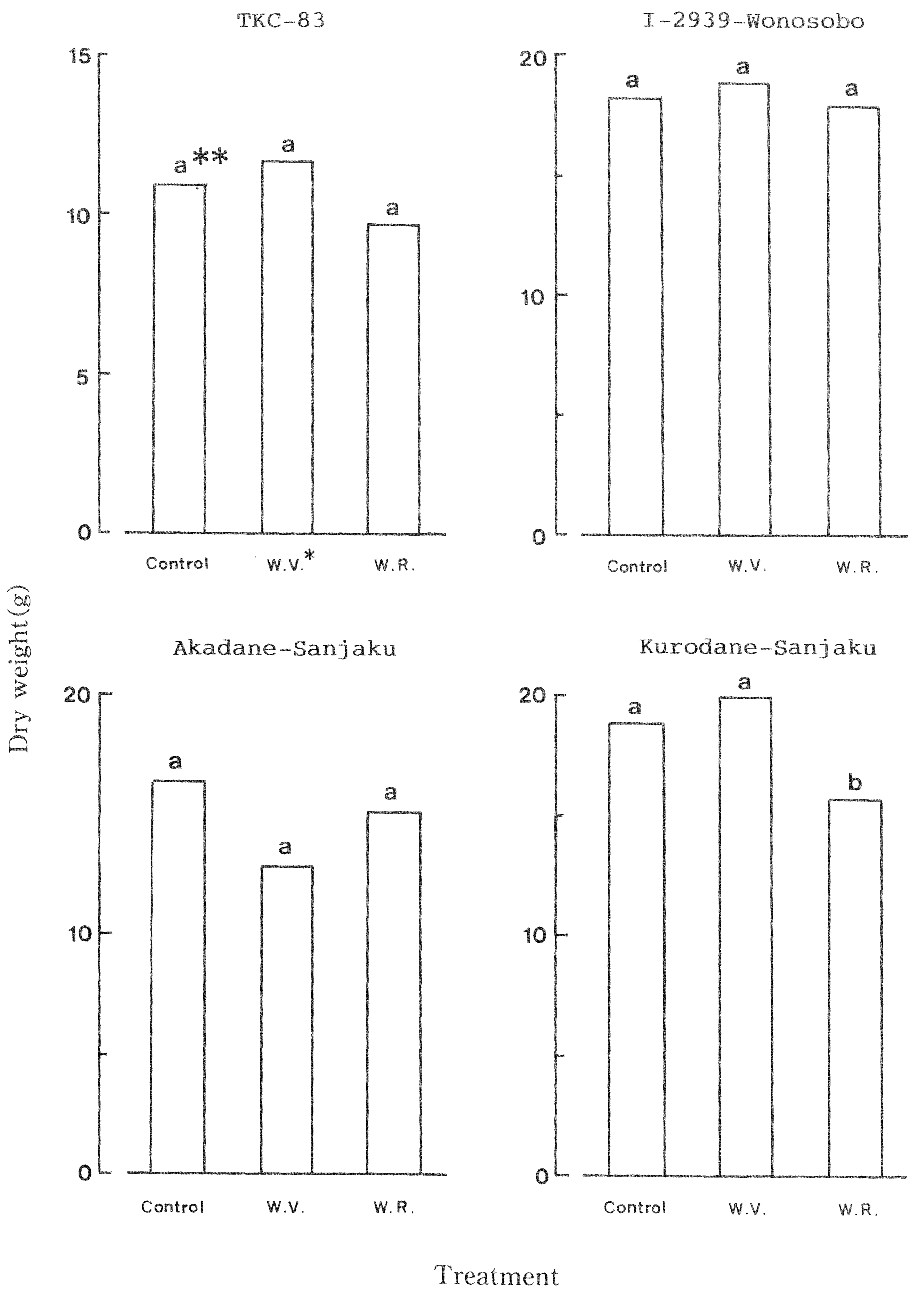

Fig. 4 **Effect of short-term waterlogging at different stages on seed yield in several varieties of yard long bean**

*W. V. ; waterlogging at the vegetative stage.
W. R. ; waterlogging at the reproductive stage.
** Different letters indicate significant difference at $p=0.05$.

yield in various crops (Krizek, 1982). Once soil is waterlogged, the air space is displaced with water, and the O_2 remaining in the soil is quickly depleted by the respiration of plant roots and soil microorganisms with slow diffusion of atmospheric O_2. Thus plant roots are suddenly exposed to anaerobic conditions and growth and development are inhibited (Kawase, 1981). At the same time, the anaerobic conditions affect the activities of soil microorganisms and change the biological environment of plant roots drastically. The adverse effects of waterlogging on plant growth result directly from restricted root growth caused by the suppression of aerobic respiration, and indirectly from the interaction of plant and soil microorganisms (Gliński and Stepnięwski, 1985 ; Nawata and Shigenaga, 1988).

The finding that the elimination of indirect influences by soil microorganisms and proper supply of nutrients enabled yard long bean plants to survive under prolonged waterlogging condition prompts to reconsider the role of soil microorganisms in waterlogging damage. Although further studies should be carried out, the incorporation of the activities of soil microorganisms into plant response to waterlogging should not be overlooked.

For efficient breeding and selection, the accurate evaluation of the ability of plants to adapt to waterlogging conditions is needed. Considering the role of microbial factors, the adaptability of roots to anerobiosis should be investigated under conditions where the influences of microorganisms are removed. Then in the second step the effects of microorganisms should be evaluated. In leguminous vegetables, the role of nitrogen-fixing rhizobia is especially important for their growth and the interaction between these bacteria and plant response to waterlogging should be studied separately from that of the other microorganisms.

As stated before, waterlogged plants are subjected to dual stress, i.e. the first stress associated with soil anaerobiosis and the second associated with the removal of the stress. Under actual field conditions, since most vegetables experience only transient or short-term waterlogging, the tolerance to the second stress (which may be called "recovering ability") is more important than that to the first stress (which may be called "surviving ability") in breeding for waterlogging.

The fact that the short-term waterlogging effect depended on the stage of growth and the genotypes, emphasizes the effectiveness of breeding and selection of tolerant varieties, and also gives useful suggestions on cultural practices to minimize waterlogging damage. For instance, the increase of the plant density may be useful for stabilizing the yield, because short-term waterlogging resulted in a decrease of the yield of some varieties by restricting lateral shoot development. Adjustment of the planting date is also useful for minimizing the damage, if a given variety shows a sensitive period and if the occurrence of heavy shower is anticipated.

In some regions of tropical Asia, production systems have been developed to adapt plants to environments in which waterlogging is expected to occur frequently. Vegetable-producing areas near Bangkok in Thailand (Nawata, 1986) and floating islands in the Inlay Lake in Burma (Hsan, 1988) are representative examples. Inundation of whole field before planting in the former case, and burning of field before planting in the latter case, appear to enable vegetables to grow without sustaining flooding damage. Detailed survey on plant management in these areas should supply information about the development of cultural practices for minimizing waterlogging damage.

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Discussion

Imai, H. (Japan) : The recovery of root damage from waterlogging may be associated with the development of new roots adapted to flood conditions. Under field conditions, flood damage is serious due to the marked decrease in soil Eh by the activity of microorganisms and flood itself (chemical damage). Therefore, it would be desirable to study the relationship between the decrease in soil Eh and the extent of damage in the presence or absence of microorganism activity.

Answer : Thank you for your comment.

Johansen, C. (ICRISAT) : What is the relative effect of waterlogging on the nitrogen fixation process versus plant growth *per se* in view of the fact that N_2 fixation in some tropical legumes is very sensitive to waterlogging?

Answer : When waterlogging is prolonged, root nodules are destroyed. The effect of short-term waterlogging is rather complex. The extent of damage caused by waterlogging depends on the growth stage of the plant and soil constituents. In a previous experiment there was no difference between the plants which received inorganic nitrogen and the nodulated plants (yard long bean). In cowpea, however, short-term waterlogging affected more adversely the nodulated plants.