Monitoring Soybean Tolerance to Flooding Stress by Image Processing Technique

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Abstract…

Flooding is a common environmental stress that suppresses plant growth. This study was conducted to test the use of machine vision extracted plant features for early, non-contact, and quantitative detection of flooding stress. Top projected canopy area (TPCA) of soybean plants during the two-week flooding and one-week recovery period was obtained by an image processing technique. Flooding stress induced plant movement determined by TPCA was decoupled from plant diurnal movement and plant growth using coefficient of variation of TPCA (COV_{TPCA}). Threshold value of COV_{TPCA} as an indicator of flooding stress was determined by a parametric approach. The effectiveness of the sensing technique for early, quantitative detection of stress was compared with the leaf photosynthetic rate and plant biomass. The results indicated that early, non-contact, quantitative detection of flooding stress by TPCA was feasible.

Introduction…

In addition to normal diurnal movement, leaves also move in response to biotic stresses. Oosterhuis et al. (1985) reported that under drought stress soybean leaves are oriented more erectly such that the average leaf-stem angle became smaller as the leaf water potential and soil water potential declined. The advancement of machine vision imaging has allowed more precise detection and quantification of leaf movement under control and stressed conditions. Seginer et al. (1992) followed the vertical movement of the tip of fully expanded tomato leaves using machine vision imaging and reported that the movement can be used as indicator of incipient drought stress before the appearance of visual wilt symptoms. As the leaves move, the boundary moment of its top projected canopy area (TPCA) changes. Nyakwende et al. (1996) reported that the boundary moments detected by machine vision were correlated with drought stress. Kacira (2000) computed the top projected canopy area (TPCA) and its coefficient of variation (COV) for control and drought stressed New Guinea Impatiens plants. By using the parametric approach to establish the baselines for early water stress detection, this technique can detect drought stress from 5 to 29 h before the onset of visual wilt symptoms.

The use of machine vision to detect leaf movement in response to flooding stress has not been studied. Since excess water due to flooding damages roots and produces wilt symptoms similar to drought stress, it is hypothesized that TPCA can be used to quantify responses of plant to flooding stress. This research was conducted to determine the TPCA of two soybean genotypes during the two-week flooding and one-week recovery of two soybean genotypes, one was more tolerant to flooding than the other. The TPCA responses were compared with photosynthetic rate and biomass.

Materials & Methods…

Growing conditions

The study was conducted in a walk-in growth chamber set at constant 24 ± 1°C and 14 h light (140 W m^{-2}). Six pots (15 cm in diameter) each containing three plants were placed at 60° apart on a computer controlled turn-table (0.90 m in diameter) powered by a stepper motor (MD2-a, Arrick Robotics Inc., Hurst, TX) **(Figure 1)**. The turn-table rotates the plants continuously at six revolutions per hour to provide more uniform growing conditions to the plants and to move the plants individually to a monochromatic CCD camera for image acquisition.

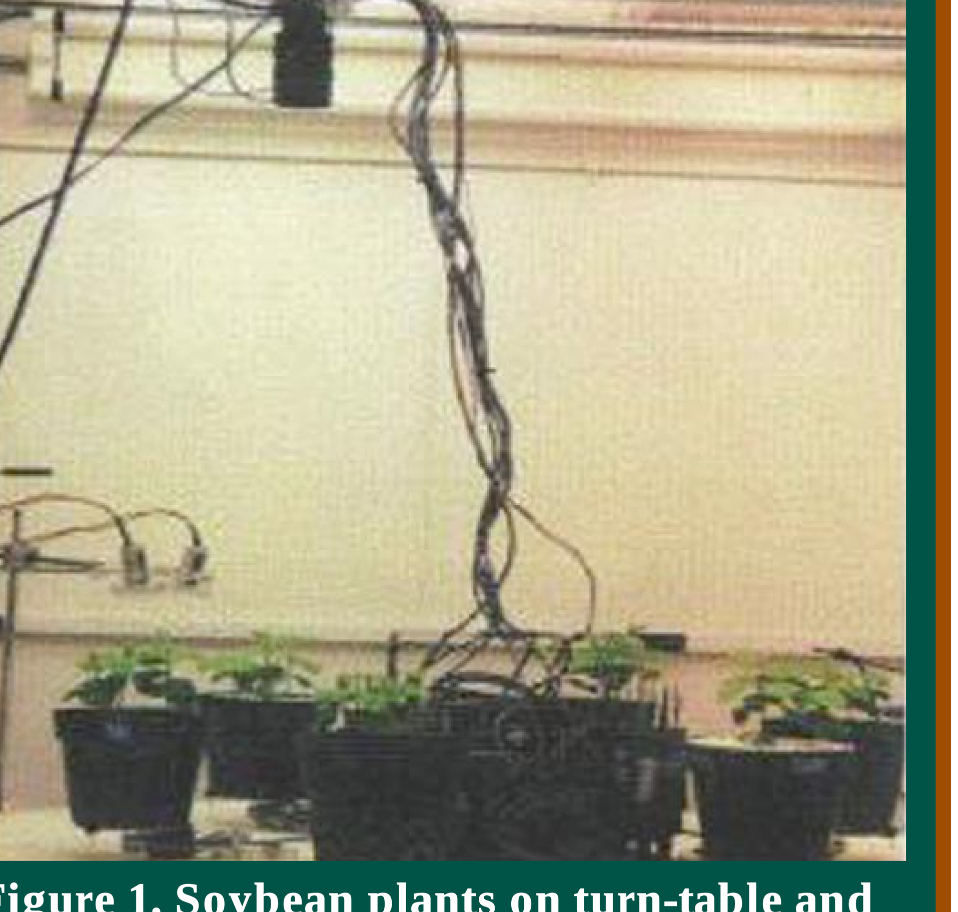


Figure 1. Soybean plants on turn-table and CCD camera for image acquisition.

Plant materials and flooding treatments

Seeds of two soybean genotypes 157 and 107 were germinated and grown in 15 cm-diameter pots at three plants per pot until the plants were 3 weeks old. The plants were exposed to either flooding alone (FA) or flooding covered Styrofoam beads (FS). Plants of the control treatment were not flooded.The Styrofoam layer created a more hypoxic root environment by reducing the air exchange between the water and the atmosphere fivefold. The experiment was repeated two times, each with three plants. Flooding continued for two weeks. The pots were then drained and allowed to recover for one week. After flooding, the plants were fertilized with Miracle Grow (Scotts Miracle-Grow Products, Port Washighton, NY) as described by the manufacturer. Photosynthetic rate was determined with an ADC Photosynthesis Meter Model LCA-2(The Analytical Development Co. Ltd., Haddesdon, England) at three time points: before flooding, after two weeks of flooding and after one week of recovery. Root and shoot were harvested and dried for biomass determination.

Image acquisition and analysis

The image acquisition system consists of a monochrome CCD camera (Pulnix TM-200, Pulnix America Inc., Sunnyvale, CA) and a personal computer equipped with a 640 x 480 x 8 resolution frame grabber board (Matrox Meteor II Standard, Matrox Electronic Systems Ltd., Quebec, Canada). The camera, mounted perpendicular to the turn-table at 1 m height, captured four consecutive images of the top view of each pot every 10 mins when the pot was positioned directly under the camera.

Images of the top canopy projected area (TCPA) were analyzed using the image processing software Visilog 5.1 (Noesis S.A., Velizy, France). The mean TCPA of each time point was computed from the four images taken at that time point.

The plant movement during the light period was adjusted for random noise by the formula:

$$\text{Movement}_I = (\text{TPCA}_I - \text{TPCA}_{average})/\text{TPCA}_{average} \times 100\%$$

Results & Discussion…

Figures 2 and 3 show the canopy movement of the genotype 157 and 107 plants during two weeks of flooding and one week of recovery, respectively. The movement of the canopy determined in this study reflected the diurnal movement as well as movement due to changes in leaf turgor (i.e. wilting) and movement due to growth. During the first seven days of flooding stress, the FS plants of genotype 157 showed the most movement as determined by the amplitude of the chart, followed by plants of the FA treatment (Figure 2). The movement reflected leaf wilting and drooping rather than the normal growth showed by plants of the control treatment. During the last 7 days of the flooding stress, movement of stressed plants was reduced to the same level as the control plants, reflecting the acclimation to stress. After the withdraw of flooding and with additional nutrients, both control plants and plants that recovered from the stresses showed more movement indicating growth during the recovery time. Similar pattern of canopy movement was also detected with genotype 107 (Figure 3). However, in this genotype, canopy movement of the FS and FA treatments was similar during both flooding and recovery periods.

Figure 2. Canopy movement of genotypes 157

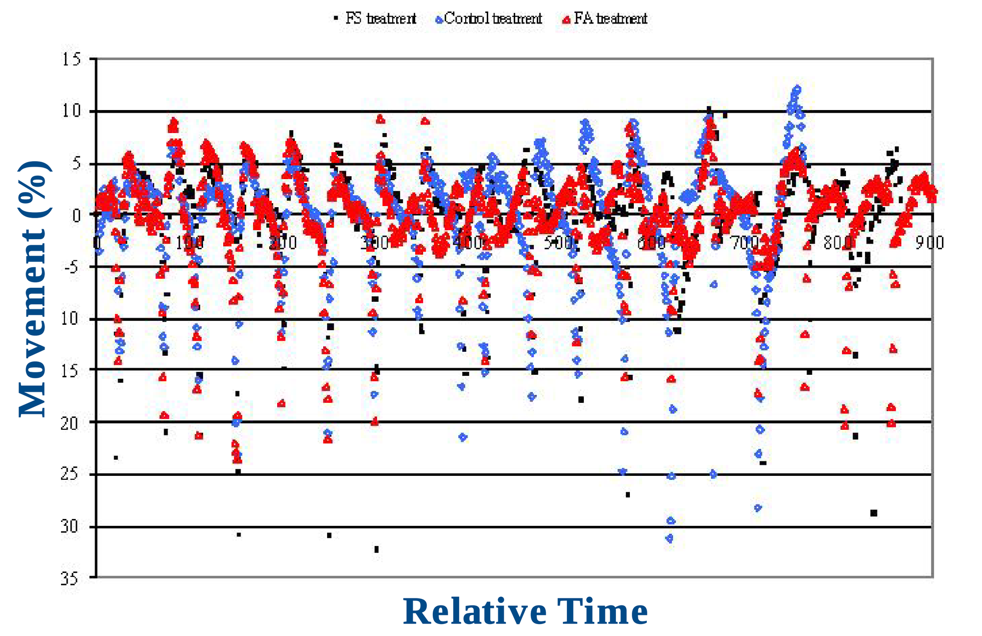
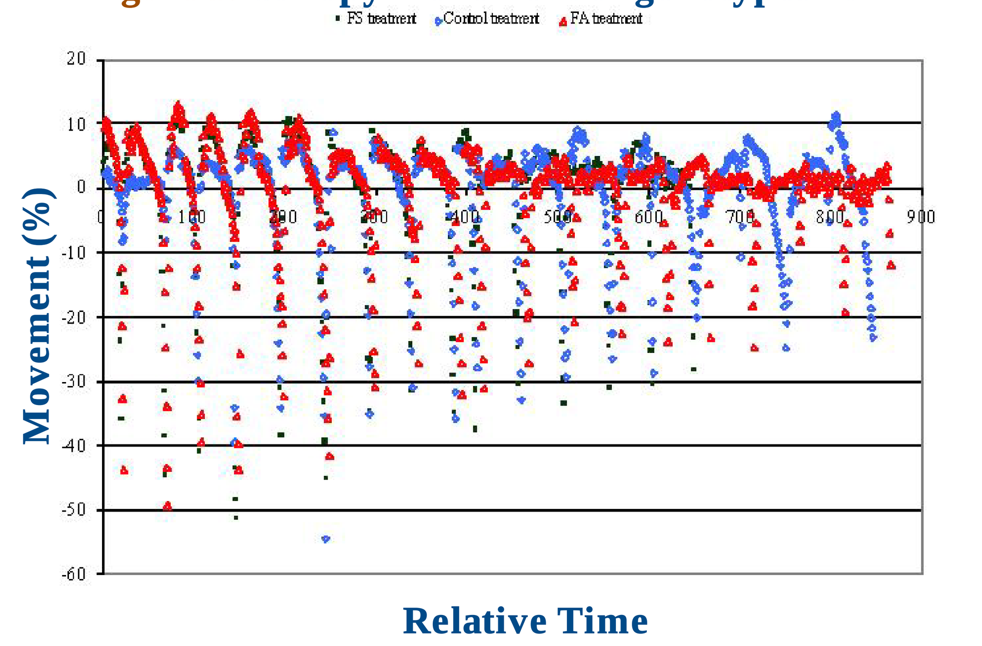


Figure 3. Canopy movement of genotypes 107



Figures 4 and 5 show the average TPCA values of genotypes 157 and 107 during the flooding and recovery periods, respectively. The canopy growth of both genotypes, reflected by the slope of the TPCA graphs, showed three distinct phases. During the first five days of the experiment, control plants of genotype 157 (Figure 3) grew rapidly at a linear rate. Plants of the FA treatment grew at a slower rate, while plants of the FS treatment did not grow. During the last 9 days of flooding, canopy expansion stopped in all treatments including the control, which displayed lack of nutrient symptoms. After the removal of stress and addition of nutrients, plants resumed growing again. Plants of the genotype 107 also showed the three-phases growth curve. However, no difference in growth was detected between the FS and FA plants during flooding stress. During the recovery, plants of the FA treatment grew the most followed by plants of the FS and control treatments.

Figure 4. TPCA of genotypes 157

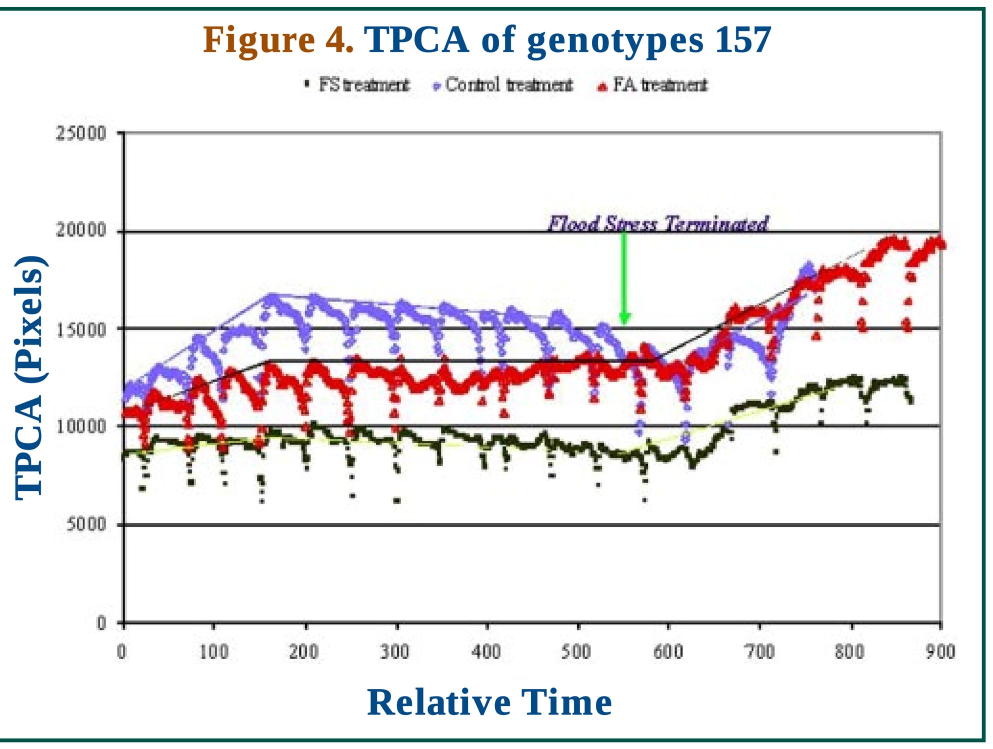
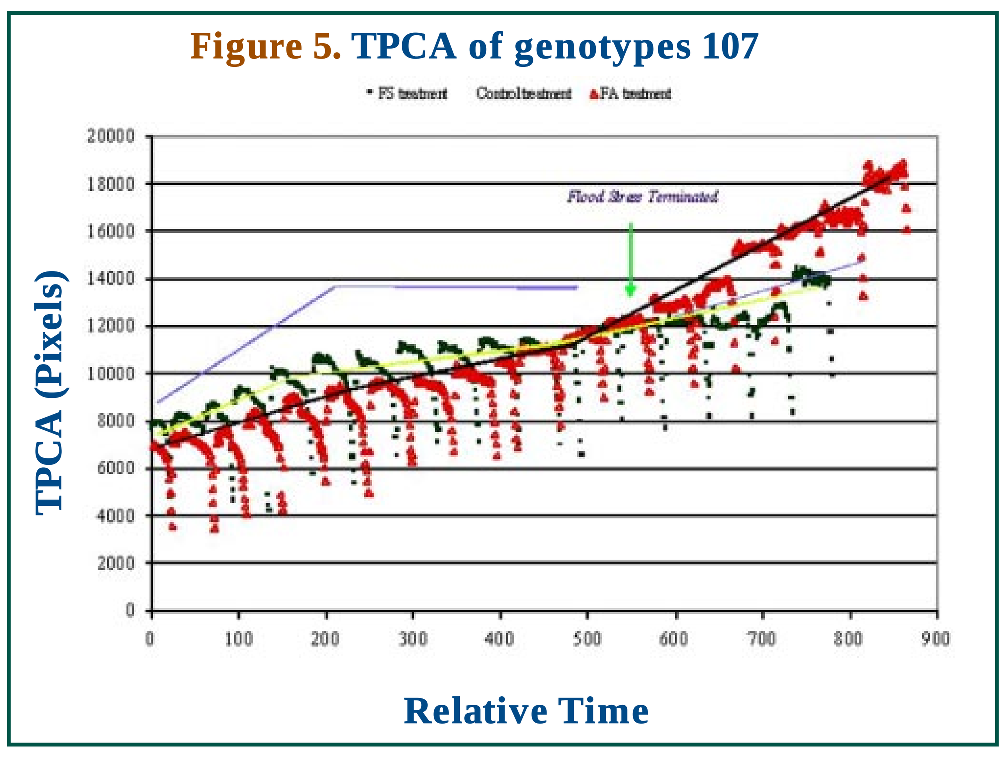


Figure 5. TPCA of genotypes 107



The average photosynthetic rate of genotype 107 and 157 before flooding, after flooding and after recovery is reported in **Table 1**. Photographs of the plants were taken at the end of the recovery period **(Figure 6)**. Plant biomass collected at the end of the experiment is reported in **Table 2** together with the TCPA growth determined during the first five days of flooding stress.

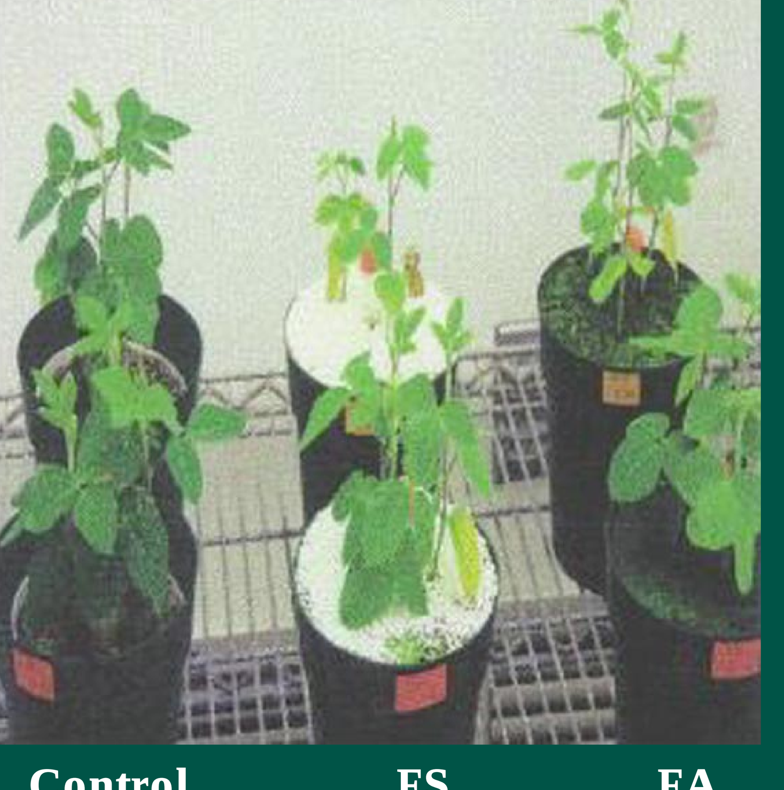
Table 1. Responses of two soybean genotypes to flooding (FA) and flooding plus styrofoam (FS) treatments as determined by photosynthetic rate Photosynthetic rate (mg $CO_2/cm^2/$ h)

	Before flooding				After flooding				After recovery			
Genotype	107		157		107		157		107		157	
Treatment	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control	4.60	0.33	3.39	0.50	4.89	0.01	3.88	0.56	3.52	0.75	3.37	0.32
FA	5.04	0.38	3.16	1.48	4.32	1.66	4.87	0.85	3.51	0.37	3.02	0.22
FS	5.75	0.23	2.95	1.39	2.27	0.45	2.26	0.85	1.75	0.28	2.62	0.49

Table 2. Responses of soybean genotype 107 and 157 to flooding (FA) and flooding plus styrofoam (ST) treatments as determined by TCPA and biomass

Treatment	TCPA (pixels)		Biomass (g/plant)			
	107	157	107		157	
			Mean	SD	Mean	SD
Coontrol	3750	4000	3.01	0.38	3.32	0.13
FA	1750	1650	3.04	0.14	2.43	0.21
FS	1750	600	2.87	0.50	1.67	0.06

Figure 6. Soybean plants at the end of the experiment.



Conclusion…

The results indicated that the FS treatment was more detrimental to soybean growth than the FA treatment and that genotype 107 was much more tolerant to FA and FS treatments than genotype 157. The TPCA detected by machine vision showed rapid movement of soybean leaves in response to flooding stress. The magnitude of the movement is proportional to the stress levels indicating that the possibility of using TPCA to quantify the tolerance of soybean to flooding stress exists.

References…

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