Evaluation of plant root system complexity under heavy metal stress based on fractal analysis

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1.Introduction

Cadmium (Cd) is one of the most toxic heavy metals to plants, especially has negative effects on root system. Cd accumulates greater in roots than the other organs in plants. The architecture of the root system is a critical factor for the acquisition of nutrient and water. Although there have been some conventional methods to measure root system such as dried biomass, length and root number counting, those methods cannot estimate the complexity of the root. Therefore, a method to estimate the development of the root system is required. Fractal geometry is a quantitative method to describe complex natural objects with non-integer dimensions[1]. The objective of this study is to examine the developmental responses of root systems for Cd stress based on fractal geometry.

2.Experiments and results

In this study, the roots of wheat (*Triticum spp.*) which germinated in a hydroculture system were used as samples, and effects of Cd on fractal dimension (FD) of the root system were estimated by exposing their roots to $CdCl_2$ solution over 9 weeks. The images of root systems were digitized by using camera, and skeletonized following the binarization as a preprocessing for fractal analysis.

The FD of skeletonized images were obtained according to the box-counting method[1]. The FD takes unity for a simple line object and increases towards 2 as the complexity of the object increases, ($1 \leq FD \leq 2$).

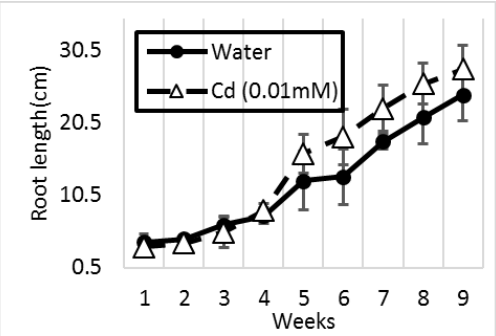

Fig.1 Root length change

Fig.1 shows the root length for 9 weeks under different concentrations of Cd, 0 and 0.01mM. It can be seen that the root became shorter for first 3 weeks due to the influence of Cd compared to the control (0mM). Figs.2(a), (b) show the skeletonized images of root system at 3rd week for 0 and 0.01mM Cd, respectively. It can be seen clearly that the complexity of the root structure is lost due to Cd. Fig.3 shows the dependence of FD on the concentration of Cd. There was a clear reduction in FD compared with the control, and the deduction rates were 37%, 52%, and 61%, respectively, 0.001, 0.01, and 0.05mM. Figs.2(c), (d) show the skeletonized images of control and 0.01mM Cd concentration at 5th week. More interestingly, even though the root lengths under Cd were found longer than the control from 4 to 9 weeks, a clear complexity reduction could be seen after Cd exposure with the root length average reduction rates of 8.81%, 23.22%, 29.70%, 20.51%, 17.99% and 12.79%, respectively.

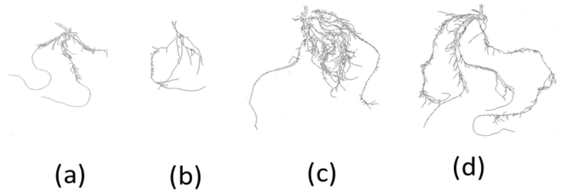

Fig.2 Skeleton images of (a) control and (b) under 0.01mM Cd at 3rd week, (c) control and (d) under 0.01mM Cd at 5th week.

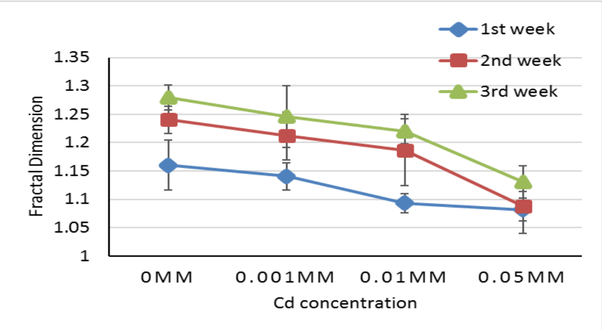

Fig.3 FD for wheat root skeleton images for different Cd concentration

3.Conclusion

In this study, fractal dimension was used to evaluate the root architecture of wheat under Cd exposure. The results imply that fractal dimension can be an effective measure for the structural development of the root system under heavy metal stress, and FD was found to be more sensitive to reflect the influence of the heavy metal than the conventional measure.

References

1. Mandelbort, B.B., 1983. The fractal geometry of nature. Freeman,