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FELLOWSHIP FINAL REPORT

Plasma Technology and Application in Agriculture with AI approaches

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ABSTRACT

Plasma technology can be applied in different stages of agricultural production with increasing yield and improving quality. The promotion effect of plasma on agriculture depends on the plasma treatment parameters and effective methods of plasma diagnostics. In order to obtain optimized plasma treatment parameters and identify plasma agricultural objects, it is necessary to combine with artificial intelligence (AI), which can play an important role in plasma diagnosis and plasma agricultural applications. In our studies, plasma discharge spectra were effectively identified by building an AI model. In order to identify agricultural objects by plasma treatment at different stages of agricultural production, different AI models were constructed, showing the effectiveness of AI in plasma agriculture. These results also show the practical application and advantages of the plasma-agriculture-AI multidisciplinary combination.

1- Introduction

The widespread use of fertilizers and pesticides in agriculture has indeed boosted crop growth, greatly contributing to the increase of agriculture production, but it has also caused a series of problems, such as environmental degradation, soil fertility decline and the increasingly food safety problems. Thus, innovative green technologies that can improve agricultural productivity are greatly needed.

Plasma consists of ions, electrons, free radicals, ground, excited state molecules, and so on. It easily reacts with the surface of the substance it contacts. Up to now, it has achieved good applications in the fields of material processing, environmental remediation, biomedicine, agriculture and food. Low temperature plasma (LTP) technology is a green agricultural technology with high efficiency and without causing environmental pollution. Since the overall gas temperature of LTP can be as low as room temperature, great progress has been made in the research on the application of LTP technology in agriculture. Many studies have shown that the application of LTP technology in agriculture can increase agriculture yield and also improve agriculture quality.

However, there is a lack of research on the identification and classification of plasma-treated agriculture objects. With the development of artificial intelligence, it is feasible and effective to build models to recognize agricultural objects treated by plasma. In addition, as the agricultural production level improved, plasma technology is expected to be used in agriculture on a large-scale, which also needs the combination with artificial intelligence.

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We conducted the investigations on plasma technology (including experiments, simulations, and diagnostics, etc) , plasma agricultural application, and the interdisciplinary combination with AI technology. The application prospect of these studies were also analyzed.

2- Experimental details

Discharge experiments in different discharge systems such as dielectric barrier discharge (DBD), radio frequencey (RF) and so on were conducted. The effects of different experimental parameters including power, gas and gas pressure on plasma discharge characteristics were investigated. The diagnostic methods including discharge patterns from direct discharge image observation, spectra analysis and so on were used to analysize plasma discharge characteristics. For example, taking the ethylene RF discharge experiment as an example, plasma diagnostics can be carried out by combining the emission spectrum data collected by a spectrometer with the discharge patterns collected by an image acquisition system.

In various discharge conditions, atmospheric plasma can bring a lot of convenience due to plasma can be realized in an open space under atmospheric temperature and pressure. Thus, it has good application prospect in agriculture. In our experiments, atmospheric plasma treatments on agriculture seeds (including rice seeds, wheat seeds and vegetable seeds, etc.) were conducted, then then the treated seeds were used in field planting experiments to study the effect of plasma on the subsequent agricultural production process.

In addition, the degradation of imidacloprid pesticide aqueous solution was also conducted in an atmospheric DBD plasma. The effects of DBD discharge parameters, temperature and initial concentration on the degradation ratio were investigated. The degradation products were analyzed with the help of high-performance liquid chromatography and mass spectrum.

The combination of plasma disagostics and agricultural application with AI strategies were also studied through constructing the corresponding models.

3- Results and discussion

For plasma diagnostics, the discharge spectra analysis in the experiment of ethylene RF discharge was carried out and the corresponding spectral data under different pressures was obtained. An ethylene plasma spectrum recognition model was constructed and compared with common machine learning models, showing our propsed model has the highest recognition accuracy (about 99%). The feature importance and the correlation between the intensities of the important wavelengths and gas pressures were also analyzed. This study showed an efficient plasma spectral recognition method.

For the effect of plasma treatment on seeds, Chinese cabbage was chosen as one kind of treated vegetables in an atmospheric DBD plasma and planted in Beijing. The growth speed and nutrition were studied. Dry weight and the contents of vitamin C, soluble sugar and total amino acids were used to indicate the quality and nutrition of the treated Chinese cabbage. The results show that plasma can positively adjust the growth and quality of vegetables. It is due to that during the direct treatment of seeds in atmospheric LTP, the produced large amounts of active RONS including O, OH, O_3, H_2O_2 , NO, N_2O, HNO_2 and so on) can positively affect the seed surface including contamination of seeds,breaking of dormancy, enhancement of seed germination and seedling growth.

In our studies, plasma seed treatment was also conducted on rice crop and the rice field planting experiments were conducted in three cities of China. The whole growth process from sowing to harvesting was observed, and the growth data and nutrition data of each stage

were collected. In order to recognize and classify plasma treated rice, AI models were proposed. Such as, at the tillering stage, an effective multiscale shortcut convolutional neural network was constructed to classfify plasma rice; At harvest stage, a plasma rice yield prediction model based on bi-directional long short-term memory artificial neural network is constructed, which can well predict plasma rice yield. In order to recognize plasma rice after harvest, a rice hyperspectral image classification model based on multilayer perceptron network and residual learning is proposed, showing its good recognition effect with the higher recognition accuracy and lower model complexity than other models.

For plasma pestcide degradation, the imidacloprid degradation in an DBD plasma was studied. The effects of DBD discharge parameter, temperature and initial concentration on the degradation ratio were investigated. It showed that plasma treatment can effectively degrade imidacloprid and the degradation effect depends on the initial concentration of imidacloprid as well as discharge voltage and time. Four new degradation products were generated. Under the proper plasma parameters, the degradation ratio can be up to 98%. The increase in temperature caused by plasma discharge only affects the degradation ratio by a few percent. These results show that LTP has the potential to be an effective imidacloprid degradation method. In order to quickly detect the degradation ratio of imidacloprid, a model with the effectiveness and good performance by the combination of Fourier transform infrared spectral data and one-dimensional convolutional neural network was proposed, which provides a new method for pesticide detection.

4- Conclusion

Plasma technology were applied in different stages of agricultural production with increasing yield and improving quality. The improvement effect of plasma seed treatment on vegetable and crop growth were studied in experiments. The imidacloprid pesticide degradation by plasma treatment was also studied in experiment. The promotion effect of plasma on agriculture depends on the plasma treatment parameters. In order to obtain optimized plasma processing parameters and identify plasma agricultural objects, it needs to be combined with artificial intelligence. Plasma discharge spectra analyses and recognition as well as their combination with AI were conducted. In order to recognize or classify plasma treated agriculture objects, different AI models were constructed, showing the effectiveness of AI in the practical application of plasma agriculture.

5- Perspectives of future collaborations with the host laboratory

The future collaborations with the host laboratory include promoting student exchange, common publications including comparative study of plasma developed in China and in France, applying collaboration projects of short term actions, organize a new session of on-line meeting on the topic of AI for plasma science, designing and implementing plasma physics and plasma applications in zero-gravity conditions.

6- Articles published in the framework of the fellowship

Some results under the current theme have been published or accepted for publication in academic journals, such as the effect of plasma application on the growth and nutrition in Chinese cabbage (IEEE Transactions on Plasma Science, 50(4),2022), plasma spectra recognition (Plasma Physics Reports, 1, 2023), plasma pesticide degradation (Pol. J. Environ. Stud. 32, 2023) and its AI fast detection (Desalination and Water Treatment, 274, 2022), plasma rice recognition (IEEE Geoscience and Remote Sensing Letters, 19, 2022), plasam rice yield prediction (accepted for publicaiton by SPIE-The International Society for Optical Engineering), etc. In a word, a total of thirteen papers were published and accepted for publication, two patents were issued, four

software copyrights were registered, a contributed oral talk was given in an international conference. The publications are shown in the referenences [18]-[37].

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