Agriculture and Food Sciences Research
Vol. 11, No. 2, 110-115, 2024
ISSN(E) 2411-6653/ ISSN(P) 2518-0193
DOI: 10.20448/aesr.v11i2.6179

Design and experimentation of a pressure testing platform for tea tree canopy

Pengfei Wang[1]
Yongguang Hu[2]
Decheng Liu[3]
Qingmin Pan[4]
Wenqiang Wu[5]

(Corresponding Author)

[1,2,3,4,5]*Jiangsu Province, Zhenjiang, Jiangsu University, China.*
[1]*Email: jsu.wpf@gmail.com*
[2]*Email: deerhu@ujs.edu.cn*
[3]*Email: 30116103@qq.com*
[4]*Email: 2112116011@stmail.ujs.edu.cn*
[5]*Email: dilanshengxue@126.com*

Abstract

In the mechanized operations of tea gardens, components like cutting blades and suspension systems frequently interact with the tea tree canopy, resulting in complex push, squeeze, and pressure interactions. This makes it challenging to accurately measure the distribution characteristics of the forces involved. The uncertainty in these mechanical properties complicates mechanical design, posture adjustment, and positioning control. To address this, this study designed and developed a testing platform for pressure measurement in the tea tree canopy, aiming to systematically investigate the force characteristics and structural changes of the canopy under different penetration depths. The platform enabling high-precision recording of canopy responses under varying pressure conditions. The experimental results indicated significant differences in pressure values at different depths and locations. At a penetration depth of 1.0 cm, the minimum pressure value was 3.0 N, while the maximum pressure at a depth of 4.0 cm reached 60.0 N. Moreover, the pressure exhibited a clear hierarchical distribution with changes in depth and position. The study observed a hierarchical structure within the tea tree canopy, comprise tender leaves, mature leaves, and branches. These findings provide important evidence and data support for the optimization of tea garden management and harvesting machinery design.

Keywords: Pressure testing, Tea tree, Hilly region, Canopy structure of plants, Testing platform design, Field experiment.

Citation | Wang, P., Hu, Y., Liu, D., Pan, Q., & Wu, W. (2024). Design and experimentation of a pressure testing platform for tea tree canopy. *Agriculture and Food Sciences Research*, *11*(2), 110–115. 10.20448/aesr.v11i2.6179

History:
Received: 24 October 2024
Revised: 27 November 2024
Accepted: 29 November 2024
Published: 2 December 2024

Publisher: Asian Online Journal Publishing Group

Funding: This research is supported by the Regional Science Foundation projects (Grant number: 32460782) and Priority Academic Program Development of Jiangsu Higher Education Institutions (Grant number: PAPD-2023-87)
Institutional Review Board Statement: The Ethical Committee of the Jiangsu University, China has granted approval for this study (Ref. No. 20241115001).
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

Contents

Contribution of this paper to the literature
The article presents a device for testing the pressure of the tea canopy layer, which analogizes the pressure test of soil and has found physical stratification in the actual observation of the tea canopy layer. Currently, there is no research on measuring the pressure and stratification characteristics of the tea canopy layer.

1. Introduction

Tea tree (Camellia sinensis) is a globally significant economic crop, playing a crucial role in the agricultural and economic systems of countries such as China, Japan, and India [1]. As the scale of tea cultivation expands and labor costs rise, traditional manual management and harvesting methods can no longer meet the demands for efficiency and scale in modern tea production [2-4]. Consequently, the development and optimization of tea garden management and harvesting machinery have become key to advancing the tea industry towards modernization and automation. However, existing tea garden management and harvesting machinery often face a major challenge: the physical damage to the tea tree canopy structure during operation, which adversely affects the health of the trees and the quantity and quality of the tea leaves. Therefore, exploring the mechanical properties of the tea tree canopy under mechanical action and optimizing machinery design to minimize damage to the trees has become a core technical issue in the mechanization of the tea industry. The structure of the tea tree canopy not only influences photosynthesis, gas exchange, and moisture management but also directly affects the forces experienced during mechanical harvesting [3]. Different tea varieties and cultivation methods result in distinct canopy structures that exhibit varying mechanical properties under external pressure, raising design requirements for tea harvesting machines [5, 6]. During the harvesting process, the canopy experiences mechanical pressures such as compression and bending. Accurately designing the harvesting head to adapt to different canopy structures and reduce unnecessary physical damage directly impacts the efficiency and effectiveness of mechanized harvesting [7, 8].

With the advancement of sensor technology and mechanical analysis methods, studying the force response of the tea tree canopy under mechanical pressure has become increasingly feasible [9, 10]. Existing studies have shown significant differences in deformation, stress distribution, and physiological responses of plant canopies under varying external forces; particularly, external pressure significantly alters the physiological activities and morphological characteristics of the tea tree canopy. Although there are various tea canopy shot detection models available [11, 12]. Research on the pressure characteristics of tea tree canopies remains limited, and there is a lack of systematic experimental platforms to dynamically monitor the behavior of tea trees under stress conditions [13, 14]. This study aims to design an experimental platform to simulate the force conditions of the tea tree canopy under different pressure levels, providing a scientific basis for the design of tea harvesting machines. The platform can precisely apply different pressure levels and monitor the stress distribution, morphological deformation, and physiological responses of the canopy in real time. It integrates stress sensors and data acquisition and analysis modules to record the stress and strain conditions of the canopy under mechanical action. This experimental platform not only offers new methods for understanding the pressure characteristics of tea tree canopies but also provides a theoretical foundation for the design and optimization of harvesting machinery. Through a systematic study of the response mechanisms of tea tree canopies under various pressure levels, this research will help enhance the operational efficiency of harvesting machines while reducing negative impacts on tea tree growth, thereby promoting the sustainable development of tea industry mechanization and achieving efficient tea garden management and harvesting.

2. Materials and Methods

2.1. Design Principle of Test Platform

The dense foliage of the tea tree canopy can be approximated as a compact solid when a large panel is pressed down upon it, resembling compressible soil [15]. This allows for the study of the tea canopy using principles similar to those applied in soil mechanics. The Bekker settlement theory is based on statistical analysis of extensive experimental data and incorporates classical theories of soil mechanics. Bekker identified essential differences in the settlement processes between off-road vehicles and structures like foundations. Structures typically apply static and heavy loads, resulting in slow settlement rates and minimal displacement, while off-road vehicles exert dynamic and lighter loads, causing rapid and significant settlement. The state of the tea tree canopy structure under pressure aligns with Bekker's settlement theory. Therefore, applying this theory to the pressure characteristics testing of the tea tree canopy aims to analyze the deformation, compression, and mechanical responses of the canopy when subjected to external pressures (such as those from tea harvesting machines or other mechanical operations). This analysis will provide insights into the growth environment of tea and optimize the equipment used, offering foundational theoretical support for the design of the pressure characteristics testing platform for tea tree canopies. A model of soil settlement under pressure is illustrated in Figure 1.

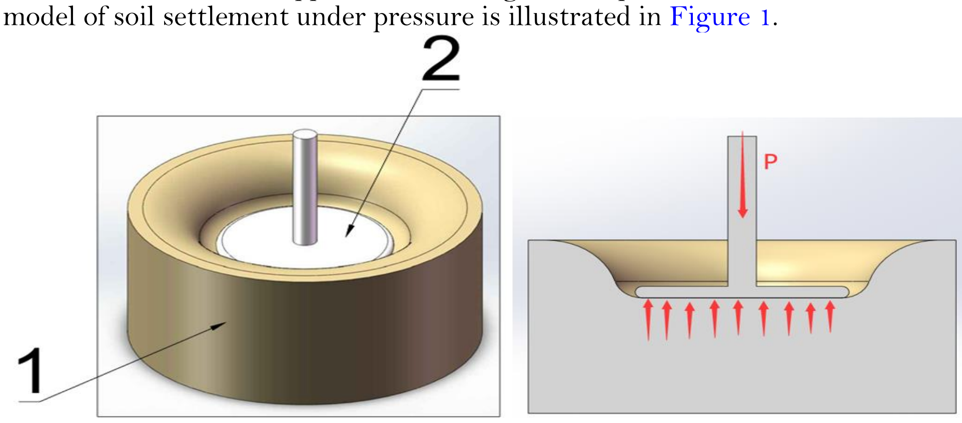

Figure 1. Schematic diagram of soil pressure subsidence.

Note: 1. soil 2. platen.

2.2. The Overall Design and Function Realization of The Test Platform

To meet the agronomic requirements of standardized tea planting models, the main functions and technical parameters of this testing platform are detailed in Table 1. The platform is designed with a gantry structure, as shown in Figure 2. It is driven by a stepper motor system allowing for three-axis movement: the Y-axis for lateral motion mounted on a moving frame; the Z-axis installed above the Y-axis for vertical movement; and the X-axis, which is fixed between two parallel Y-axes to achieve forward and backward movement. The coordinated motion of the three axes ensures precise control of speed and position for the platform.

The control system utilizes a PLC (*Programmable Logic Controller*) to send pulse signals to the stepper motor drivers, converting these signals into angular displacement signals that drive each stepper motor for accurate motion control. In the platform design, the Z-axis must support equipment weighing up to 30.0 kg, while the X-axis must carry the weights of the Y and Z axes, along with associated motors and testing equipment. To accommodate the complex terrain of the fields, the platform is equipped with a wheeled moving frame that allows for height adjustments in four directions, ensuring compatibility with uneven tea garden surfaces. The height of the moving frame is set at 1.2 meters to allow the platform to traverse tea ridges during operation.

For the canopy compression tests, a membrane-type pressure sensor is chosen to accurately measure the mechanical responses of the tea tree canopy, as shown in Figure 3. This sensor offers high precision, sensitivity, and a wide measurement range (0-100 kg), making it suitable for measuring the pressure characteristics of the canopy. Its circular membrane design, which can be either of variable cross-section or flat type, provides excellent resistance to lateral loads, ensuring the stability and accuracy of the measurement data. The compact size of the sensor allows for easy miniaturization, making it suitable for installation within the limited space of the canopy testing platform. By providing continuous and stable mechanical parameters, this sensor offers a scientific basis for analyzing the mechanical characteristics of the tea tree canopy, optimizing its structure, and enhancing both the yield and quality of tea leaves.

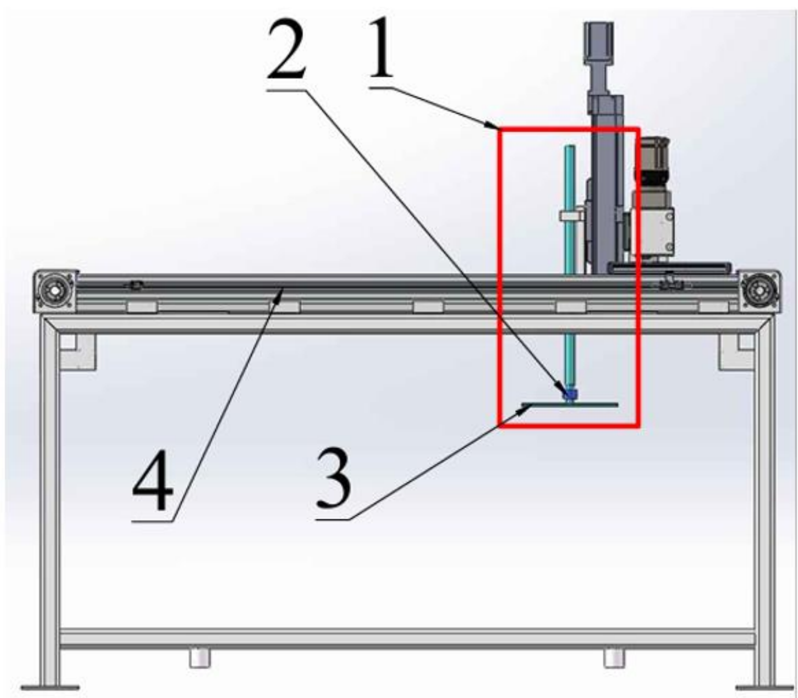

Figure 2. Side view of the test bench

Note: 1 Z-axis dynamometer, 2 pressure sensors, 3 pressure plates, 4 racks.

Figure 3. Bellows type tension pressure sensor (0-100kg/M8).

2.3. Design and Implementation of Field Experiment on Test Platform

The testing platform is illustrated in Figure 4, with dimensions of 1.5 m in height, 0.4 m in length, and 1.8 m in width. During the testing process, the measurement depth is first calibrated on the force gauge of the Z-axis, after which the pressure rod is gradually lowered to the specified depths. The collected data is transmitted in real time to a computer for recording. Once measurements at each point are completed, the platform is manually moved to the next position for further measurements.

To effectively simulate the impact of harvesting machinery on the tea tree canopy, a square wooden board measuring 20 cm × 20 cm is chosen for the pressure application. This size is determined by several considerations. First, it ensures that the pressure coverage area is moderate, effectively simulating the localized force of harvesting machines without interfering with or damaging the natural structure of the canopy due to excessive area. Second, the 20 cm × 20 cm board provides high operational convenience and accuracy for positioning, securing, and collecting pressure data. Additionally, this size is consistent with commonly used pressure plate dimensions in soil mechanics, enhancing the scientific validity and comparability of the test data. This choice not only meets the experimental design requirements but also provides a solid basis for subsequent analysis of canopy stress and optimization of equipment.

To obtain representative pressure data, adult tea trees covering all canopy levels are selected for testing. As shown in Figure 5, the platform integrates pressure sensors, a data processing unit, and a recording system, allowing precise capture of pressure changes at different depths. Measurements are taken at 12 points across the canopy cross-section to analyze the distribution and patterns of data at varying depths of application.

The zero point is established at the position where the sensor first contacts the canopy, resulting in zero pressure. Comparative data indicates that the sensor's readings are unstable at depths less than 10.0 mm, while depths exceeding 70.0 mm lead to canopy collapse, which is detrimental to cutting operations. Therefore, the final set pressure depths are established at 10.0 mm, 20.0 mm, 30.0 mm, and 40.0 mm to analyze their effects on the pressure characteristics of the Zhongcha 108 canopy.

Figure 4. Test bench and test area.

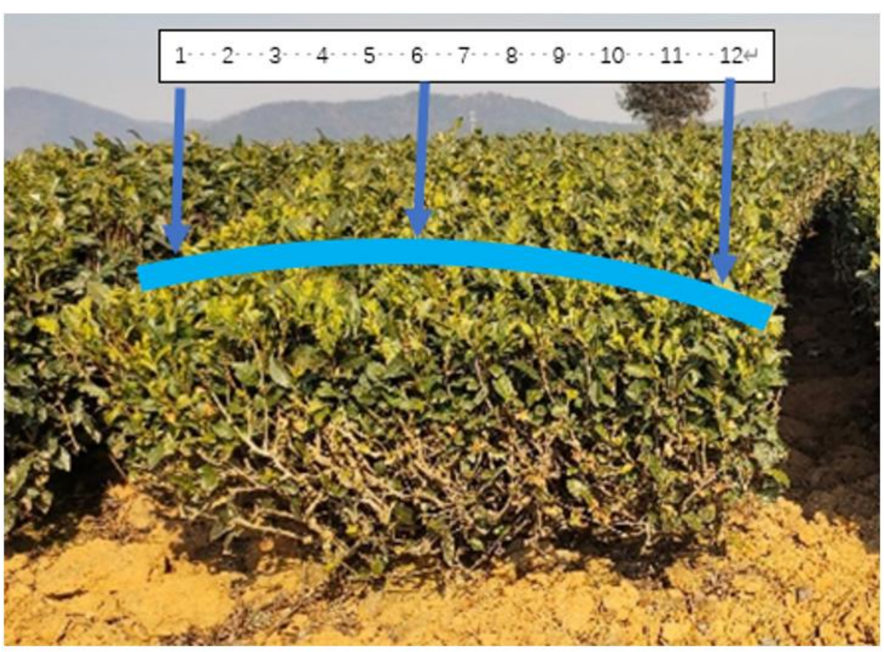

Figure 5. Location diagram of 12 collection points.

3. Result and Analysis

Using the testing platform shown in Figure 4, pressure measurements of the tea tree canopy were conducted at various compression depths, with results summarized in Table 1. Analysis of the pressure data at different depths (1.0 cm, 2.0 cm, 3.0 cm, and 4.0 cm) for each measurement point (illustrated in Figure 6) revealed a consistent pattern in pressure changes with respect to location and depth, exhibiting significant differences at varying depths. As the compression depth increased, the overall pressure values showed an upward trend, particularly at depths of 3.0 cm and 4.0 cm, where pressure changes were more pronounced. Specifically, at a depth of 1.0 cm, the pressure curve was relatively flat, with small differences in pressure between measurement points, indicating that the upper structure of the canopy was sparse. At a depth of 2.0 cm, pressure gradually increased, especially around measurement points 6 to 8, where a noticeable rise in pressure suggested an increase in canopy density in that region. At depths of 3.0 cm and 4.0 cm, the pressure curve exhibited peaks at measurement points 6 to 8, with values significantly higher than at other points, reflecting a dense middle layer structure in the tea tree canopy.

Additionally, the pressure peaks concentrated at measurement points 6 to 8, particularly at depths of 3.0 cm and 4.0 cm, where the pressure sharply increased to its maximum. This indicates that the density of the canopy in this area is significantly greater than in other regions, likely corresponding to the distribution of the main leaves and branches of the tea tree. This phenomenon highlights the layered characteristics of the tea tree canopy: the upper layer (1.0 cm and 2.0 cm) is sparse, while the middle layer (3.0 cm and 4.0 cm) has increased density. At measurement points 9 to 12, the pressure gradually decreased with position, especially at deeper measurement points, indicating that the device had penetrated through the denser parts of the canopy into the sparser lower region. Overall, the trends in pressure changes with depth and position suggest that the tea tree canopy can be roughly divided into a sparse outer layer, a dense middle layer, and a sparse lower layer, exhibiting significant stratification. In future research, accumulating more pressure data will facilitate a quantitative assessment of the tea tree canopy structure and the establishment of a canopy pressure model. In agricultural machinery operations, real-time monitoring of compression depth and pressure changes can assist in precisely locating equipment within the canopy, supporting accurate pruning and harvesting of tea trees while enhancing operational precision and efficiency. This finding provides essential theoretical and practical support for the application of smart agricultural equipment in tea tree management. The layered structure of the tea tree canopy is distinctly illustrated in Figure 7. From top to bottom, the canopy can be divided into layers of tender leaves, mature leaves, fine branches, and old branches, with differences in physiological function and growth state across layers. This stratification is a result of the tea tree's natural growth characteristics and pruning management, reflecting the process by which tea farmers optimize harvesting efficiency and improve tea quality. The successful design of the pressure testing platform for the tea tree canopy lays a solid foundation for future large-scale experiments. Upcoming work can involve accumulating pressure data across broader tests to refine the canopy pressure model, providing precise design guidelines for intelligent harvesting equipment. Furthermore, the analysis method based on pressure data demonstrates good versatility, making it applicable to various tea tree varieties and growth environments, thus offering data support for mechanized harvesting under diverse conditions.

Table 1. Corresponding table of pressure/depth of tea canopy.

Depth/cm	Pressure/N											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1.0	3.0	3.0	3.0	7.0	5.0	10.0	3.0	6.0	10.0	10.0	4.0	4.0
2.0	9.0	8.0	14.0	17.0	18.0	22.0	24.0	15.0	18.0	16.0	10.0	8.0
3.0	13.0	13.0	16.0	21.0	25.0	31.0	35.0	30.0	21.0	24.0	14.0	15.0
4.0	17.0	26.0	21.0	27.0	30.0	43.0	60.0	40.0	30.0	28.0	25.0	18.0

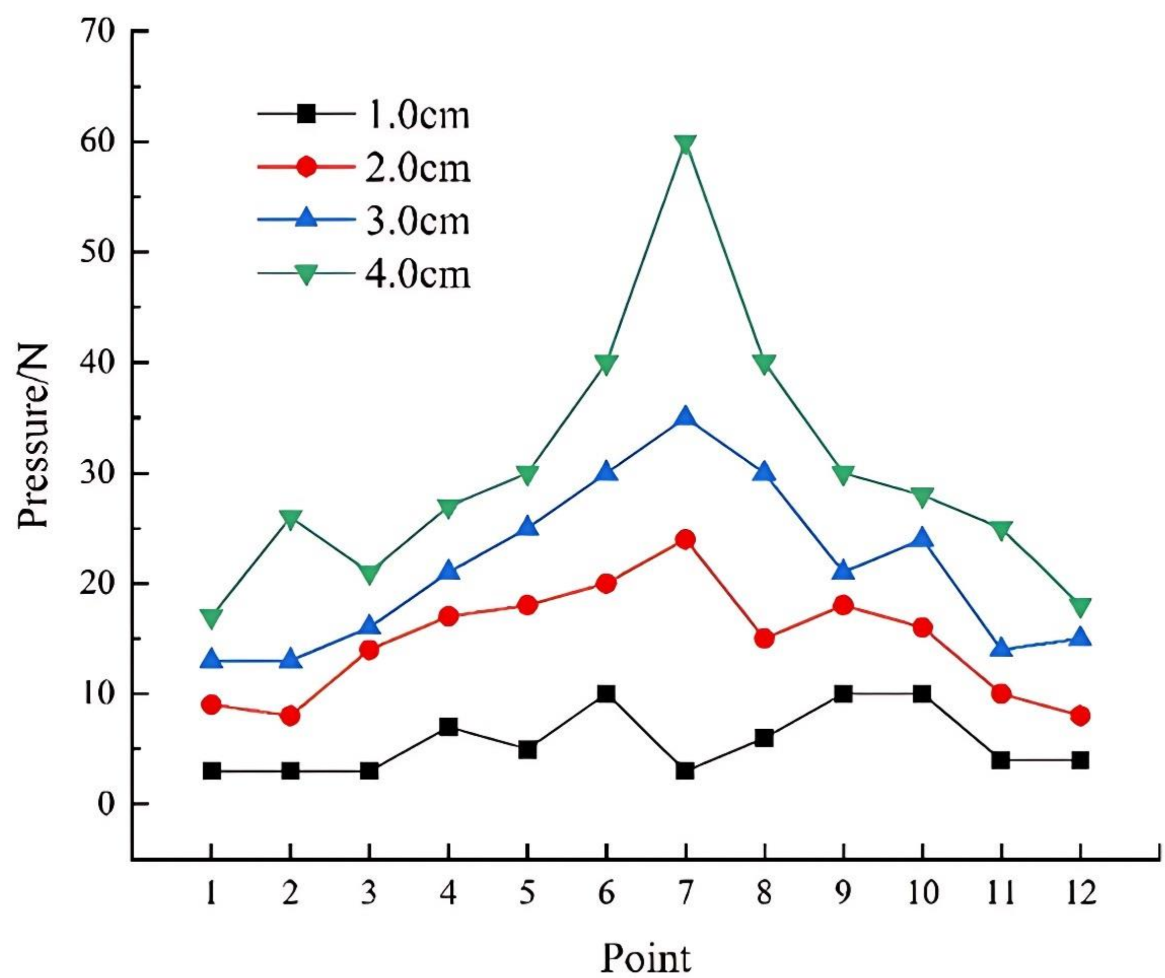

Figure 6. Measurement results of tea canopy pressure at the same pressure depth.

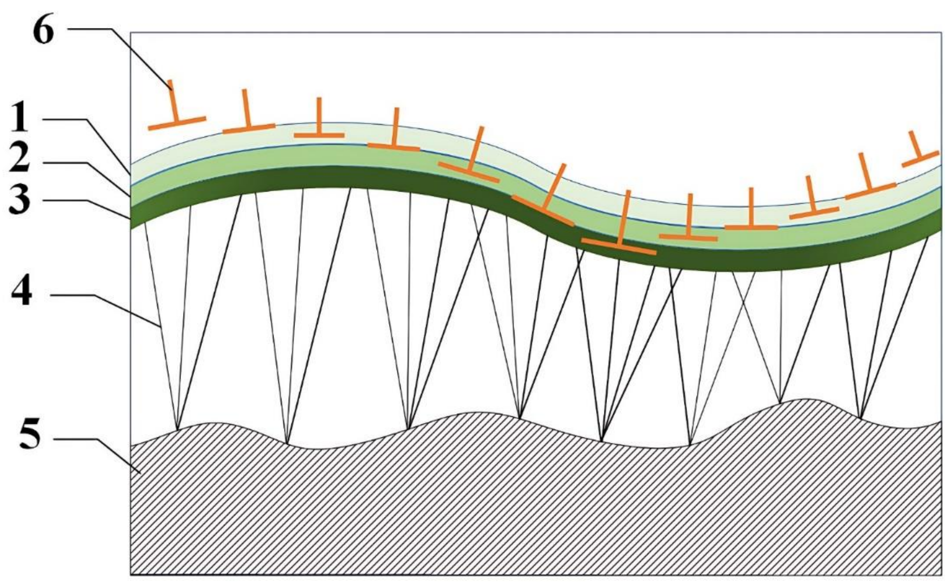

Figure 7. Schematic diagram of longitudinal section of tea row.

Note: 1 Tender layer、2 Old leaf layer、3 Twig layer、4 Old branch layer、5 Ground、6 Twelve pressure sensor and its position.

4. Conclusions

The pressure collection system designed in this study demonstrates stable performance and effectively gathers pressure data from the tea tree canopy at various compression depths. Data analysis reveals the pressure distribution characteristics of the canopy structure at different locations and depths, confirming the non-uniformity of canopy density. Notably, localized areas exhibit peak pressure values, indicating a dense structure within the canopy. These findings provide critical references for understanding canopy characteristics and optimizing the design of tea harvesting equipment. The pressure data analysis enables a more accurate assessment of the specific location of machinery within the tea tree canopy, enhancing operational effectiveness. Pressure feedback allows the machinery to adjust operations in real time, facilitating more precise execution of harvesting tasks while minimizing disruption to the deeper canopy structure, thus improving positioning efficiency and protecting the healthy growth of the tea trees. This study deepens the understanding of the tea tree canopy structure and provides a scientific basis for the optimized design of intelligent tea harvesting equipment. By analyzing how pressure varies with depth, harvesting machinery can execute tasks more efficiently and intelligently, significantly contributing to the modernization, intelligent transformation, and sustainable development of the tea industry.

References

[1] G. Meirion-Griffith and M. Spenko, "A modified pressure–sinkage model for small, rigid wheels on deformable terrains," *Journal of Terramechanics*, vol. 48, no. 2, pp. 149-155, 2011. https://doi.org/10.1016/j.jterra.2011.01.001

[2] S. Ihara, S. Furuhata, S. Noda, H. Nagai, Y. Kikuchi, and F. Tatsuoka, "Estimating the compacted dry density of gravelly soil with oversized particles," *Transportation Geotechnics*, vol. 49, p. 101379, 2024. https://doi.org/10.1016/j.trgeo.2024.101379

[3] J. C. García-Peña, J. G. Ramírez-Gil, C. Góngora-Canul, L. Calderón, J. Cuellar, and C. Cruz, "Multiscale temporal and spatiotemporal analysis of wheat blast infection-like dynamics using vertical plant stratification, regression and Markov chain approaches," *Plant Pathology*, vol. 72, no. 9, pp. 1570-1584, 2023. https://doi.org/10.1111/ppa.13789

[4] M. De Cristofaro *et al.*, "Modeling the excess porewater pressure buildup in pyroclastic soils subjected to cyclic loading," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 150, no. 12, p. 06024007, 2024. https://doi.org/10.1061/jggefk.gteng-12129

[5] W. Wenchao, "Reciprocating cutting mechanism and parameter optimization based on load pattern and bending deformation of tea stalks," Doctoral Dissertation, Jiangsu University, Zhenjiang Jiangsu China, December, 2023.

[6] Z. Zhang, Y. Lu, M. Yang, G. Wang, Y. Zhao, and Y. Hu, "Optimal training strategy for high-performance detection model of multi-cultivar tea shoots based on deep learning methods," *Scientia Horticulturae*, vol. 328, p. 112949, 2024. https://doi.org/10.1016/j.scienta.2024.112949

[7] T. Jing, Z. Tang, Z. Ding, Y. Liang, M. Fang, and T. Wang, "Paddy soil compaction effect undergoing multi-dimensional dynamic load of combine harvester crawler," *Agriculture*, vol. 14, no. 2, p. 202, 2024. https://doi.org/10.3390/agriculture14020202

[8] U. Veyna, S. Garcia-Nieto, R. Simarro, and J. V. Salcedo, "Quadcopters testing platform for educational environments," *Sensors*, vol. 21, no. 12, p. 4134, 2021. https://doi.org/10.3390/s21124134

[9] W. Yan, H. Wu, Y. Qu, and Y. Yan, "Design of hydraulic driving experimental bench for automatic vertical drilling tool," presented at the In Journal of Physics: Conference Series (Vol. 1314, No. 1, p. 012121). IOP Publishing, 2019.

[10] J. Zehui, "Optimal parameter design on fracture tea-picking device for famous and high-quality tea," Master's Thesis, Jiangsu University, Zhenjiang Jiangsu China, September, 2023.

[11] Z. Zhang, Y. Lu, and Y. Zhao, "Ts-yolo: An all-day and lightweight tea canopy shoots detection model," *Agronomy*, vol. 13, no. 5, p. 1411, 2023. https://doi.org/10.3390/agronomy13051411

[12] D. H. Liu, X. Xiao, and L. Q. Yin, "Research on adaptation of machine picking in Yunnan tea garden," *Shandong Agricultural Science*, vol. 47, no. 4, pp. 49-51, 2015. https://doi.org/10.14083/j.issn.1001-4942.2015.04.013

[13] M. R. Esmaeili, R. Khodabakhshian, and M. Khojastehpour, "Effect of asafoetida extract solution on red apple quality with a focus on the mechanical properties of peduncle, rate fruit drop and orchard pest control," *Applied Fruit Science*, pp. 1-11, 2024. https://doi.org/10.1007/s10341-024-01205-6

[14] H. Adèle, C. Buffet, P. D'Arras, A. Bourmaud, and C. Baley, "Winter flax: Stem structure, fibre properties and reinforcement potential for composite materials," *Industrial Crops and Products*, vol. 217, p. 118831, 2024. https://doi.org/10.1016/j.indcrop.2024.118831

[15] M. Islam, A. G. Nizar, and R. Stefan, "A case study on advanced CPT data interpretation: From stratification to soil parameters," *Geotechnical and Geological Engineering*, vol. 4, no. 5, pp. 4087-4113, 2024.