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Editorial

Soil Mechanical Systems and Related Farming Machinery

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The mechanization of agricultural work has contributed significantly to the improvement of agricultural productivity and reduced production costs. Recently, its importance has been highlighted owing to the shortage of agricultural labor, especially in developing countries where urbanization is progressing rapidly [1,2]. Since the beginning of mechanization, various types of farming machinery related to soil preparation, sowing, fertilization, pest control, harvesting, and post-harvesting have been developed. In addition, customized farming machines suitable for the cultivation type and soil characteristics of each country and region have been developed [3]. Unlike other industrial machinery, farming machinery targets living organisms and operates on the soil; therefore, it should be designed considering its interaction with the soil. Thus, it is essential to understand the characteristics of both the soil and mechanical systems to optimize the design of farming machinery. This Special Issue covers the design, analysis, and testing of all types of farming machinery, with an in-depth understanding of soil and mechanical systems.

This Special Issue contains 14 papers, with 12 research articles, one communication article, and one technical note. The authors are from five countries: Indonesia, Iran, Poland, South Korea, and Ukraine. In terms of machines, agricultural tractors, rotavators, garlic planters, vegetable transplanters, pot-seeding machines, and machine vision systems were included. Design, measurement, simulation, and theoretical analyses were conducted to develop advanced farming machinery techniques and to extend the understanding of the interaction between soil and mechanical systems in farming machine applications. The papers in this Special Issue can be grouped into three categories: advanced farming machinery techniques, soil–machine interaction research, and soil property research.

The first category includes advanced farming machine techniques. This includes the development of novel or improved mechanical systems, advanced measurement and simulation methods, and the investigation of the characteristics of farming machines using theoretical or experimental methods. Eight papers were included in this category, half of which were related to agricultural tractors.

Kim et al. presented a modified method to improve the accuracy of a three-point hitch dynamometer, also known as a six-component load cell, for measuring the precise traction force of agricultural tractors [4]. They suggested modified force and moment equations that could consider the geometry and tilt of the dynamometer under real installation conditions. The accuracy of the modified method was verified through an actual field test. This study is important because accurate knowledge of the operating force is crucial for the application of smart farming technology that requires the precise control of attached implements, as well as for the optimal design and efficient use of agricultural tractors.

Unlike Kim et al. [4], who focused on measuring the traction force, Lebedev et al. analyzed the effect of a coupling weight to increase the traction efficiency of agricultural tractors by reducing the uneven distribution of vertical reactions between the wheels [5]. They employed theoretical and comparative analyses by incorporating existing scientific findings related to agricultural tractors operating in traction mode. This study revealed

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that agricultural tractors with a center of mass offset to the front or rear axles had the highest probability of equal distribution of vertical reactions between the wheels of one axle, and agricultural tractors with a center of mass in the middle between the axles had the lowest probability. In addition, this study found that agricultural tractors can operate with maximum traction efficiency when the front and rear axles are locked during plowing work, with an uneven load distribution on the sides. Although further verification is required under conditions with various installed implements, this study provides good insights into the effect of an agricultural tractor's coupling weight and center of mass on traction performance.

Lim et al. developed a finite element (FE)-based simulation model of an agricultural tractor's frame-type rollover protective structure (ROPS) to replace a real ROPS test with a virtual simulation [6]. This study presents methods for developing 3D models of ROPS and setting the load and boundary conditions to accurately simulate the force and deformation applied to the ROPS. The accuracy of the proposed method was verified using actual test results. Virtual simulation technology for the ROPS of agricultural tractors can make significant savings in time and cost, and is also very important in terms of safety. Many developed countries are conducting research to develop this technology, and this study provides important technical information.

Ahn et al. investigated power loss in the dual-clutch transmission (DCT) of agricultural tractors using theoretical and experimental approaches considering the oil circulation effect [7]. Power losses in all of the components of the DCT, such as gears, shafts, bearings, clutches, and brakes, were calculated using the ISO standard and viscous fluid theory, and the theoretical analysis result was verified through an experiment using a three-axis dynamometer system. This study revealed that the oil level of the transmission system, oil circulation conditions, and operating characteristics of the transmission components, such as rotation speed, are important factors for power loss and transmission efficiency. This study has important implications as the interest in DCT and energy conservation is increasing worldwide.

Cho and Yang developed a real-time, low-cost, and high-throughput plant phenotyping system for commercial plant factories that can determine crop growth information, such as fresh weight, leaf length, leaf width, and number of leaves [8]. The developed system is composed of a low-cost phenotype sensor network with an integrated Raspberry Pi board and a camera module that allows easy modification depending on the crop growth environment. The applicability of the system is validated through experiments on Batavia lettuce cultivated in a plant factory. The cost-effective and highly productive characteristics of the developed system can be distinguished from those of existing phenotyping systems. The ripple effect of this research is significant, as it can be applied to all types of crop cultivation facilities, including smart farms.

Lim et al. studied garlic planters [9]. This study presented a simulation method using the discrete element method (DEM) to optimize the bucket size of the finger-type metering device. For highly accurate simulation results, techniques for creating 3D models of garlic cloves and buckets, deriving the physical and mechanical properties of garlic cloves, and setting the contact conditions between the garlic cloves and bucket were presented. The simulation method presented in this study was validated through experiments using an actual garlic clove and bucket. As a result of this study, the authors were able to obtain the optimal bucket size with a plant rate of 97.5%. Recently, DEM have been widely used in simulations of the interaction effects between farming machinery and soil or agricultural products, and this study provides important information for correctly applying DEM.

In countries such as Korea and Japan, where the per capita cultivation area is not large, vegetable transplantation is often performed using semi-automatic vegetable transplanters. Markumningsih et al. investigated the power consumption, static safety factor, and fatigue life characteristics of cam- and four-bar link-type transplanters during operation [10]. Each characteristic was measured and analyzed through extensive field tests using numerous sensors attached to the transplanter components. This study expands the understanding of the operating characteristics of semi-automatic vegetable transplanters, as well as the measurement and analysis techniques for the consumed power and static and dynamic safety of farming machines.

A mechanical pot-seeding machine was used to sow seeds into pot trays for transplanted crops. Plastic pot trays are currently being used, but are known to cause environmental problems. Hwang et al. developed an auto-feeding device for a mechanical pot-seeding machine applicable to paper-based biodegradable pot trays [11]. An auto-feeding device is used to supply pot trays individually in the first part of the mechanical pot-seeding machine, and a design appropriate for the physical and mechanical properties of the pot tray is essential. The authors designed and manufactured an auto-feeding device using mechanical and kinematic theories after measuring the properties of biodegradable pot trays. The performance of the developed device was evaluated through an actual test. The results of this study can be applied to technology for future environmental conservation.

The second category is soil–machine interaction research. It deals with the interaction effect between soil and mechanical systems, including the performance of machines that vary depending on the soil properties or the properties of soil that vary depending on the machine characteristics. Four studies were included in this category, all of which were related to agricultural tractors.

Bae et al. developed a traction force prediction model for agricultural tractors as part of a simulation study using DEM [12]. They presented a technique for modeling virtual soil environments in a simulation based on measured soil properties to obtain accurate simulation results. The traction force of an agricultural tractor during moldboard plow operations was simulated by considering the interaction between the soil and the plow blade. The simulation results were validated through an actual field test, which revealed higher accuracy than the existing empirical equation. Although the authors noted that further research is required to improve the prediction accuracy, this study provides good insight for simulating the interaction between soil and mechanical systems using DEM. This study can also be used as a reference for future digital twin modeling techniques for agricultural machinery.

Emission regulations for agricultural tractors are becoming stricter worldwide as concerns about environmental pollution increase. The load factor (LF) of agricultural tractors, which is the ratio of the actual engine power to the rated engine power, is an important indicator of air pollutant emissions. To obtain a more realistic LF in agricultural tractors, Min et al. investigated the effects of soil physical properties on the LF through extensive experiments under various soil conditions [13]. The results confirmed that soil variables had a significant influence on the LF, although the impact varied depending on the soil type. The authors noted that further research is needed to collect LF data under a wider range of tractor operating and soil conditions to improve reliability. This study has important implications related to environmental regulations of agricultural tractors.

Tillage is an essential agricultural task for the preparation of proper soil environments for crop growth. It is usually conducted by agricultural tractors with implements such as plows and rotavators, and the interaction between the soil and implementation has a decisive impact on tillage performance. Kim et al. analyzed the effects of the tillage type and gear selection on the workload of agricultural tractor–implement systems during rotary tillage [14]. The soil properties and mechanical operating characteristics were simultaneously considered to derive conclusions through extensive field experiments. The authors concluded that both the soil and mechanical conditions significantly influenced the tillage workload. The quantitative measurement results of this study can be used as reference data for designing agricultural tractors and implements as well as for understanding the workload characteristics during tillage operations.

Soil compaction caused by the passage of agricultural tractors has long been a subject of interest because of its significant effect on crop growth. Shahgholi et al. investigated the effects of the tire parameters of agricultural tractors on soil compaction through experiments and mathematical analysis [15]. The authors revealed that the tire size, tire inflation pressure, and number of passages are significant influencing factors of soil compaction, and their effects vary depending on the tire type and soil depth. A narrow tire is more effective for soil compaction because its soil bulk density changes significantly more than that of a normal tire under the same external offset condition. This study provides insight into the interaction between soil compaction and the mechanical or operating characteristics of agricultural tractors.

The final subject area was soil property research. It focuses on the quantification of soil properties for agricultural applications, with two papers in this category.

In precision agriculture, which minimizes the amount of input resources and maximizes production, spot-specific fertilization or variable control based on soil and crop characteristics is essential. Shin et al. developed a map of expected fertilization rates for nitrogen (N) and phosphorus (P_2O_5) based on quantified soil properties in salt-affected paddy fields [16]. The predicted N fertilization rate for the entire field was within 10.0 g to 25.7 g for each lot, whereas that of P_2O_5 was in the range of 0.68 g to 8.46 g. This large deviation indicates significant savings in resources compared to fertilizing the same amount overall. The technique used in this study can be applied to any type of fertilizer for precision agriculture.

Soil particle size distribution has a significant impact on the mechanical characteristics of the soil and its interaction with farming machines. Standard sieves were used to determine the size distribution of relatively large particles. However, for very small particles (less than approximately 5 mm in diameter), a hydrometer test is needed to determine the size distribution, which requires a considerable amount of labor and time. Kim et al. proposed a new method to determine the size distribution of small particles using a machine vision system with a red–green–blue (RGB) camera to overcome the shortcomings of hydrometer tests [17]. The experimental results demonstrate the reliability and accuracy of the proposed system, with only a 2.3% deviation from the actual particle size distribution. This study presents a novel and promising technique for assessing soil particle size distribution, which can be an alternative to traditional methods.

The papers in this Special Issue of Soil Mechanical Systems and Related Farming Machinery contain excellent research results that reflect the latest trends in the field. We are confident that this Special Issue will inspire researchers in the field and serve as excellent research reference data. We sincerely thank all of the authors who submitted their papers to this Special Issue and the reviewers of these papers for their constructive comments and thoughtful suggestions.

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