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Design, Development, and Performance Evaluation of a Trash-Board Moldboard Plow for the Interaction between Soil and Straw with Two Different Water Content Levels

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Abstract: A two-year field study was conducted to investigate the performance of a lightweight trash-board moldboard plow (with and without a trash-board), as influenced by stubble height and water content. Both fields were measured for the performance of a trash-board moldboard plow when used during the optimization of the plowing depth, the water content, and the reaction forces. The results showed that in the first year, when a trash-board was required, the results were significantly different. The fields had lower draft and reaction force in the soil with only stubble height, which was greater than that in the soil with dense straw for all water content levels. This was also observed in the second year for the whole depth. This study shows that the moldboard plow with a trash-board provided minimum draft and reaction forces with only straw and heavy straw. The results indicate that straw nearby shear significantly increased displacement for all treatments, with variance of straw nearby moldboard. Hence, the results verify that a trash-board continuously created large soil fragmentation with different water content. Straw labels create a position of straw which also allows for better results. It is important to install trash-boards with the moldboard plow for heavy straw incorporation.

Keywords: trash-board attachment; straw incorporation; moldboard plow; water content; soil

1. Introduction

The most important estimation parameters of tillage operation are efficiency, fuel consumption, and qualitative indices of technological process. However, both stubble height and stubble density affect water evaporation [1]. It is known that the draft resistance of plows, the energy requirement for plowing, the quality of plowing, and expenses depend on the plow body design, which is determined by the share-moldboard parameters and the parameters of its supporting surfaces. The tillage of soil is considered to be one of the biggest farm operations, as the tillage operation requires the most energy on the farm. The moldboard plow is widely used by farmers as a primary tillage tool. Its performance evaluation is essential in order to reduce the cost of the tillage operation [2–4]. However dynamometer is required to measure drawbar forces in field research on energy inputs for agricultural field equipment [5]. Tillage speed and depth, as well as soil bulk density, were additional variables that had a highly significant effect on displacement [6]. Kosmas has found that tillage operations transport large amounts of soil from convex slopes and deposit on concavities in hilly cultivated areas [7].

The draft requirements of tillage tools are accomplished by the sensors, which have been extensively studied by many researchers [8–11]. The results indicated that the average opening width was 40 mm, deviation of opening depth was 5 mm, cut rate of corn stubble was over 86%, and soil disturbance rate was 18%–22%. The arc blade type opener can improve the traffic ability of the seeder and the performances of opening and cutting stubbles. Therefore, it can satisfy the opening requirement of wheat no-till sowing in the hilly area in the southwest [12].

The plowing of rheological soil is a unique tillage practice in humid or water-logged agricultural production regions in China. System optimization of moldboard plow for rheological soil condition is necessary for improving its performance and providing a reduced draft and minimized energy consumption. An orthogonal test using four factors with three levels was conducted to optimize plow body structural and working parameters [13]. The moldboard plow is an instrument that is one of the most widely used machines in agricultural history. Compared with the ordinary moldboard plow, the mounted roll-over plow can work alternately because it has two groups of plowing bodies on the plow stock; it reduces the distance of the tractors and improves its efficiency [14].

There were clear differences in specific draft between the different tine and share types, the lowest specific draft recorded for the moldboard plow and the sweep share [15]. Specific draft was generally the highest for the chisel plow and the lowest for the moldboard plow and the disc harrow. The differences can probably be explained by differences in implementation geometry and mode of soil breakage. Specific draft increased with decreasing water content [16]. Due to the importance of the tillage stage, different factors should be selected for determining various tillage machineries and practices. Using the moldboard plow increases energy consumption, which decreases the impedance of soil; therefore, it is effective in improving crops' growth [17].

Crop residue standing above the soil surface is five to ten times more effective in preventing wind erosion than the same mass of residue lying flat on the soil surface [18]. Doan found that the stubble height, soil, and residue conditions affect the seeding performance, such as seeding depth and residue hair pinning. As seeding performance indicates the yield potential, knowing the benefits and limitations of no-till openers in handling different residue statuses is useful in improving the crop yields and the design of the openers [19]. It has been determined that, at the beginning of the harvesting period, when the average water content of the wheat stems is 70 mm in length (40.5%), 100 mm height stubble mass comprises 24.2% $\pm$ 1.9% of all the stem mass, and its water content is equal to 59.4% $\pm$ 2.7% [20]. It was found that residue distribution and incorporation were affected by the speed and depth of tillage operation, type of implement, soil conditions, type of crop residues, and height of stubble [21,22]. There are three important aspects of soil management that have the potential to enhance soil conservation efforts within agricultural fields: residue management, tillage roughness, and tillage erosion. Generally, the wheat is cut leaving approximately 100 mm stubble height [22]. However, high amounts of residue are not needed and part of the crop residue needs to be removed by bailing, and part of the crop residue needs to be incorporated into soil. Therefore, detailed data of soil, crop residue, and tillage tool interactions are needed. It is very difficult to acquire this data in field tests [23]. Tillage practices have a large impact on crop residue and how it is plowed vertically across the tillage depth. The direction of soil velocity was vertical to the surface of the plow, and its distribution was radiating. The distribution of equivalent stress was isocline, and the data was decreasing from the contact point to outer areas. The results of the simulation were verified by the data of experiments in a soil bin [24].

Some forms of tillage, if done too deeply or too quickly, can bury all residues to a depth even greater than that of the tillage depth, making very big clods of soil, and height forces are required so a trash-board can solve this problem by making height fragmentation soil and reduce soil resistance. Practices, such as the use of a trash-board during tillage, will increase the amount of surface residue present between and into the following growing seasons. Little research has been done to study how stubble height, soil, and straw conditions affect trash-board performance, such as depth, force requirement, soil fragmentation, straw burial, and straw movement. Lightweight trash-board moldboard plow performance indicates the yield potential and operation cost. Knowing the benefits and limitations of trash-board in handling different residue statuses is useful in improving the soil fragmentation and protect soil. Implements and their uses have the greatest influence on the draft requirement for tillage with the most common tillage tools. To fill in the gaps in the data, a research program was carried out to investigate the performance of the lightweight trash-board on the wheat stubble height, tillage depth, low speed on straw displacement, and two different water content levels. This was done by measuring plow draft requirement and vertical reaction (suction) for different combinations of depth and low speeds of operation under practical edaphic conditions. The problem with the moldboard plow is that the implement tends to cut both the residue and isolates in the soil, trans-locate, burying the soil. This plow has a lesser effect on straw incorporation and poor traction efficiency. Therefore, a detailed study on tillage tool–soil–crop residue interaction under controlled conditions is required. We aimed to acquire the necessary data rate commonly used with plow designs and to identify any required modifications. Therefore, the objectives of this study were to: investigate a trash-board influenced by stubble heights and soil resistance with two different water content levels; examine the correlations between soil strength, soil movement, and a trash-board; and study the effects of plowing interaction on soil and straw displacement with and without a trash-board.

2. Results

2.1. Soil Water Content

In both years, wheat had more flat residue and standing residue above ground. When the residue was removed, the soil water content at 0, 100 mm, and 150 mm in depth was highest in 2013, followed by 2014 for both years (Figure 1), which have *F* value = 0.999, *F* Critical = 0.336. This trend was possibly attributable to the taller standing stubble which trapped a layer of still air close to the soil surface and slowed down the evaporation of soil moisture. A layer was 20 mm for each, 30% average moisture for 2013, and 24% average moisture for 2014 (Table 1).

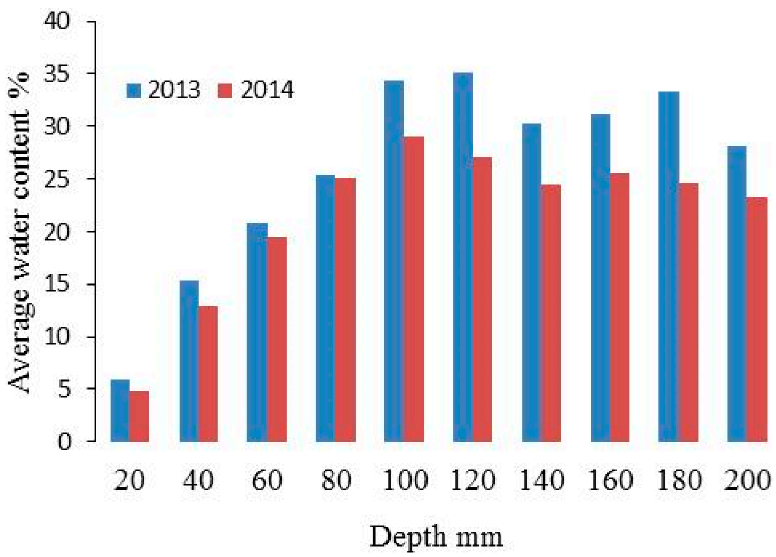

Figure 1. Gravimetric soil water content at the time of testing in experiments: for 2013 and 2014.

Table 1. Main soil strength parameters and average value of soil bulk density on each 20-mm layer.

Layers mm	2013			2014		
	Normal	Dry Bulk	Wet Bulk	Normal	Dry Bulk	Wet Bulk
	Stress (kPa)	Density g/cm^3	Density g/cm^3	Stress (kPa)	Density g/cm^3	Density g/cm^3
20	0	1.07	1.49	0.00	0.26	1.05
40	83	1.22	1.51	30	0.30	1.20
60	75	1.96	1.42	60	0.28	1.14
80	68	1.10	1.55	60	0.32	1.27
100	144	1.13	1.83	68	0.35	1.39
120	386	1.14	1.81	212	0.40	1.58
140	651	1.22	1.85	204	0.45	1.81
160	606	1.84	1.98	333	0.44	1.76
180	545	1.97	2.03	568	0.47	1.86
200	727	2.27	2.020	569	0.51	2.03

2.2. Soil Forces on the Trash-Board Moldboard Plow at 30% Water Content and Tool Parameters

Soil forces on the surface of moldboard plow with and without a trash-board at 30% average water content with a standard deviation of 2.1%, different depths of operation and two straw conditions are shown in Figure 2, which have *F* value = 0.788, *F* Critical = 0.355. This indicates that, at a depth of 15 cm, soil forces were 2794.883 N with a trash-board under dense straw cover and 3248.87 N without a trash-board at the same height. The results were 2345.686 N with a trash-board under only the stubble condition and 2760.805 N without a trash-board, respectively. It was observed that minimum forces were applied on the plow with a trash-board in stubble condition (WTNS), while maximum forces were applied on the plow without a trash-board in dense straw cover (WTOHS). Similar trends were observed at 5 cm and 10 cm operating depths, respectively. The data shows that using a trash-board decreased soil force requirements at 30% water content (Figure 3). Attaching the trash-board with the moldboard plow is important where straw cover was dense [25,26].

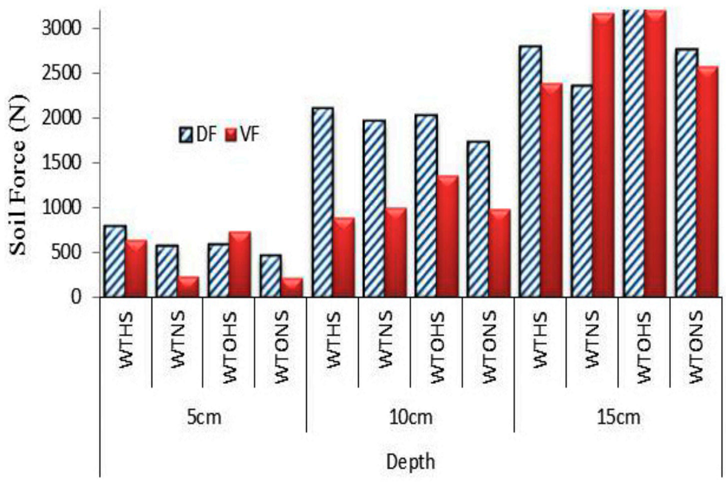

Figure 2. Soil force at 30% water content and tool parameters with different straw conditions and different depths. WTNS: plow with a trash-board in stubble condition; WTONS: plow without a trash-board in stubble condition; WTHS: plow with a trash-board in dense straw cover; WTOHS: plow without a trash-board in dense straw cover (WTOHS).

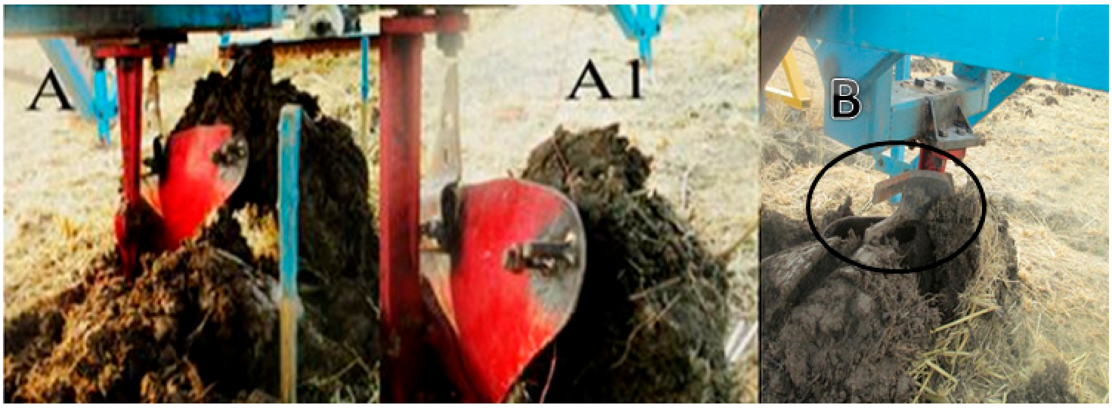

Figure 3. Comparison between attached trash-board (**B**) and without a trash-board (**A**,**A1**).

2.3. Soil Forces on the Trash-Board Moldboard Plow at 24% Water Content and Tool Parameters

Figure 4 shows soil forces on the surface of a moldboard plow with and without a trash-board at 24% average water content. It had a standard deviation 1.2%, with two straw conditions which have *F* value = 0.552, *F* Critical = 0.355. The data indicates that, at the depth of 15 cm, soil forces were 1794.883 N without a trash-board, 150 mm in straw height, and 1248.87 N with a trash-board at the same height. The results were 1345.686 N with a trash-board, 0 mm in straw height, and 1060.805 N without a trash-board, 0 mm in straw height, respectively. It is observed that minimum forces were applied on the plow without a trash-board in stubble condition (WTONS), while maximum forces were applied on the WTOHS. Similar trends were observed at 5 cm and 10 cm operating depths, respectively; thus, using a trash-board with low water content increases soil force requirements. When comparing the usage of a trash-board with two different water content levels, we suggest that it is better to use it with high water content. The statistical analysis of the data was highly significant ($p < 0.01$).

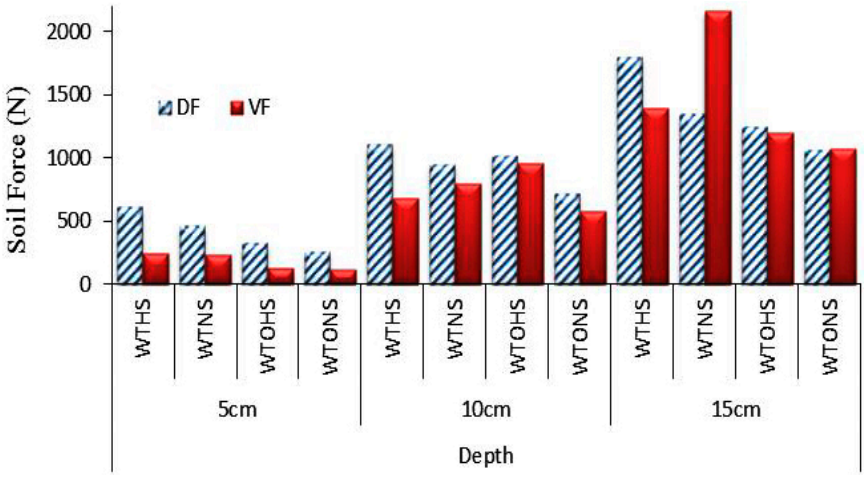

Figure 4. Soil force at 24% water content and tool parameters with different straw conditions and different depths. WTNS: plow with a trash-board in stubble condition; WTONS: plow without a trash-board in stubble condition; WTHS: plow with a trash-board in dense straw cover; WTOHS: plow without a trash-board in dense straw cover (WTOHS).

A trash-board displaces large amounts of soil from a convex slope, which changes soil properties to those less favorable for wheat production. Application of the obtained empirical functions shows that this occurs under existing climatic conditions and management practices. It has been demonstrated through experiments that the use of a trash-board creates further fragmentation in the soil on both the soil water content and the straw condition. The above results verify that trash-boards continuously created large fragmentation, compared to cases when a trash-board was not used under the same conditions. Moreover, the findings of Yousef Abbaspour *et al.* [22] concluded that an increase in soil water content resulted in a decrease in draft forces. However, Taniguchi *et al.* [27,28] and Olatunji *et al.* [29] observed that drafts required for a given implement are affected by the soil conditions and tool parameters.

2.4. Soil Displacement and Clod Size

Displacement of soil by moldboard plowing is an important land degradation process on agricultural soil in China. A trash-board displaces large amounts of soil. In Table 2, it has been shown that the use of a trash-board reduces the soil displacement, as indicated by the differences between the plows in without-trash and with-trash conditions. It has also been demonstrated through experiments that the use of a trash-board creates further fragmentation in the soil on both the soil water content and straw condition. The above results verify that trash-boards continuously created large fragmentation compared to cases when a trash-board was not used under the same conditions. However, the blank space was smaller when using a trash-board, and clod size was larger when not using a trash-board. The results also demonstrated that the differences of soil displacement between the plow with a trash-board and plow without a trash-board were significant. The large soil displacement in the field was potentially caused by soil rolling, as visually observed in the study. Roots in the field may hold the soil together to form root balls. These root balls might be responsible for the soil rolling. The existence of the trash-board reduced the force requirement and reduced soil resistance. The soil displacement ranged from 70 to 300 mm. Rahman *et al.* showed the average of the soil forwarded by displacement (146 mm) [30].

Table 2. Soil moisture, average soil displacement, average clods width, average clods length, and average blank spaces.

Soil Moisture	Treatments	Soil Displacement	Clods Width cm	Clods Length cm	Blank Space
30%	WTNS	48.89	21.33	27.22	6.55
	WTONS	64.22	29.78	45.33	9.56
	WTHS	46.44	20.44	48.11	10.78
	WTOHS	49.78	34.78	67.78	11.56
24%	WTNS	31.22	20.89	19.33	4.89
	WTONS	39.56	24.78	25.33	7.22
	WTHS	38.78	26.2	32.11	9.44
	WTOHS	41.44	32.11	41.56	12.56

WTNS: plow with a trash-board in stubble condition; WTONS: plow without a trash-board in stubble condition; WTHS: plow with a trash-board in dense straw cover; WTOHS: plow without a trash-board in dense straw cover (WTOHS).

2.5. Straw Displacement

A measurement of straw movement at two water contents is characterized by a high degree of variability. It appears that the forward straw displacement increases with the increase of straw length with and without a trash-board. For any straw length, using a trash-board decreased straw displacement. Lateral straw position produced significantly larger straw displacement, compared to that of using a forward method. The lateral distribution of all straw pieces applied in the center area of a plot were measured by counting the number of straw, position of label, and number of pieces located between the stems of straw. Lateral straw distribution is an indicator that shows how the straw will be redistributed after a specific tillage operation. The results showed that using a trash-board significantly decreased lateral straw displacement for all four lengths in 2013 and five lengths in 2014 because a little straw was removed to the outside of the second and third furrows, as shown in Table 3. The indictor of straw label creates the position of straw, which can be clearly seen in Figure 5. The results indicate that straw sheared nearby significantly increased displacement for all treatments, at variance of that nearby moldboard.

Table 3. Average straw displacement at tow water content by three parallel passes with and without a trash-board in the field.

Straw Length mm	Forward Straw Displacement mm				Lateral Straw Displacement mm			
	with a Trash-Board		without a Trash-Board		with a Trash-Board		without a Trash-Board	
	Nearby Shear	Nearby Moldboard	Nearby Shear	Nearby Moldboard	Nearby Shear	Nearby Moldboard	Nearby Shear	Nearby Moldboard
2013								
100	65.5 $^{(453.3)}$ a	30.8 $^{(198.1)}$ c	75.2 $^{(353.7)}$ a	38.1 (258.1A) b	38.1 $^{(353.7)}$ a	70.1 $^{(232A)}$ c	45.8 $^{(175A)}$ a	80.5 $^{(353.7)}$ a
150	70.3 $^{(165.5)}$ a	45.7 $^{(245.1)}$ b	79.6 $^{(542.8)}$ a	49.2 $^{(303.1)}$ b	49.2 $^{(198.1)}$ c	75.6 $^{(278.4)}$ c	50.8 $^{(326.2)}$ c	87.2 $^{(222.2)}$ b
250	73.4 $^{(275.7)}$ b	50.9 $^{(349.4)}$ a	83.2 $^{(324.1)}$ a	55.3 $^{(220.0)}$ c	55.3 $^{(124.1)}$ b	80.5 $^{(419.7)}$ a	68.7 $^{(295.4)}$ c	99.7 $^{(218.5)}$ a
2014								
75	60 $^{(4272.0)}$ b	28.8 $^{(353.7)}$ b	35.4 $^{(415.2)}$ a	30.2 $^{(353.7)}$ a	30.2 $^{(471.5)}$ a	65.4 $^{(298.1)}$ c	39.5 $^{(398.1)}$ c	50.6 $^{(353.7)}$ a
125	69.5 $^{(353.7)}$ a	33.2 $^{(214.1)}$ c	48.2 $^{(198.1)}$ c	39.5 $^{(254.7)}$ a	39.5 $^{(353.7)}$ b	71.9 $^{(325.7)}$ a	45.1 $^{(321.0)}$ a	58.8 $^{(353.7)}$ a
175	87.3 $^{(213.7)}$ a	45 $^{(198.1)}$ c	49.4 $^{(353.7)}$ a	50.6 $^{(198.1)}$ c	50.6 $^{(153.7)}$ a	89.2 $^{(353.7)}$ b	56.5 $^{(251.7)}$ b	66.6 $^{(214.3)}$ c
225	93.5 $^{(353.7)}$ a	57.2 $^{(353.7)}$ b	63.4 $^{(251.7)}$ c	66.1 $^{(145.4)}$ a	66.1 $^{(325.3)}$ b	112.8 $^{(323.8)}$ b	74.2 $^{(453.0)}$ c	77.8 $^{(353.7A)}$ a

A standard deviation of three replications. a, b, and c Letters following straw length show the differences of mean forward displacement over three tillage speeds among nine straw lengths, tested by two-way ANOVA with Duncan's test at significant level of 0.1.

Figure 5. An overview of the straw tracer used in the study for displacement analysis (100, 150, and 250 mm length of tracer used in 2013 with label, color and number), (75, 125, 175, and 250 mm length of straw tracer used in 2014).

3. Discussion

A trash-board, soil, and straw displacement were affected by many factors, such as water content, soil type, and crop residue conditions and operational factors. The length and label of straw impacted straw displacement, and cover was difficult to explore through field studies due to the complexity of field conditions. Field experiments can simplify a trash-board, soil, straw, and moldboard plow and control experimental factors. Consequently, it is easier to study the impact of the above-mentioned factors on soil and straw movement, compared to using and not using a trash-board. The present study utilized new experimental methods, which will facilitate research in this area in the future. Initial data on the soil and the displacement of the length of the affected hay and straw trash-board are presented. Furthermore, it is better to provide readers with information that is not similar to or referencing existing data.

4. Materials and Methods

4.1. Site

Experiments were carried out in 2013 and 2014 to investigate the effect of stubble height, water content, and straw movement on the performance of a trash-board moldboard plow under two straw conditions. The experiments were conducted on the Jiangpu experimental farm at Nanjing Agricultural University, Nanjing, China. The farm is located in a suburb of Nanjing (latitude: 32°3′4.96″ N; longitude: 118°36′38.78″ W). This area is characterized by a cold and arid climate in the winter, and a hot and heavily rainy climate in the summer. However, soil properties were shown in Tables 1 and 4.

Table 4. Measurement of soil cohesion and soil friction angle before tillage at different soil water content.

Items	2013	2014
Soil water content (%)	30	24
Soil cohesion (mPa)	51.39	46.284
Friction angle (Φ)	12.85°	7.81°

4.2. Trash-Board Description

The purposed design is based on the preliminary general field observations and requirements. The actual designs were developed after the collection of field information from the study area. The trash-board attachment was developed using Chinese manufacturing facilities and Pro Engineering software (version number 5.0, Parametric Technology Corporation, Needham, MA, USA). After development of the machine, it was field tested for its performances, potential problems, and effects on the soil crop parameters. Parameters were used (Figure 6), and Farid Eltom [26] described the shapes of the trash-board moldboard plow, which was used for data collection. The plows were mounted on a platform rig described below.

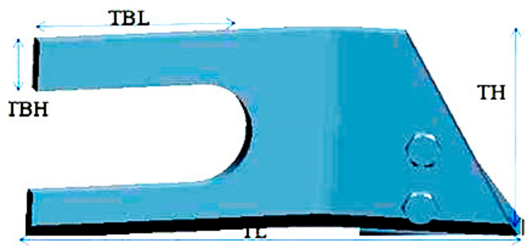

Figure 6. Schematic views of 3D solid model of a trash-boar. TL: trash length; TBL: trash blade length; TBH: trash blade height; and TH: trash height.

4.3. Design and Development of the Trash-Board for the Moldboard Plow

The design of a trash-board is a key part of plowing and directly touches the soil with the moldboard plow. This easily attached trash-board improves coverage in heavy trash stubble and stalk. It is superior to ground-penetrating covering devices, has no adverse effects on the plow, has a lighter draft, and is easier and less complicated to adjust. The trash-board creates suitable soil bed preparation for fertilizing and sowing. Its structure not only determines the shape of the trash-board but also affects its buried performance, reduces soil resistance, and increases soil fragmentations and resisting force of the whole seeder. Therefore, it affects sowing quality and the germination rate of the seed.

Pro/Engineer is a three-dimensional software designed by PTC in America. Currently, the software has been widely used in the field as part design, product assembly, model development, reverse engineering, mechanism analysis, finite element analysis, and so on. The software has been widely recognized and promoted by many companies around the world. However, though the soil model and the trash-board were drawn in Pro/ENGINEER, the steps of design are given below (Figure 7).

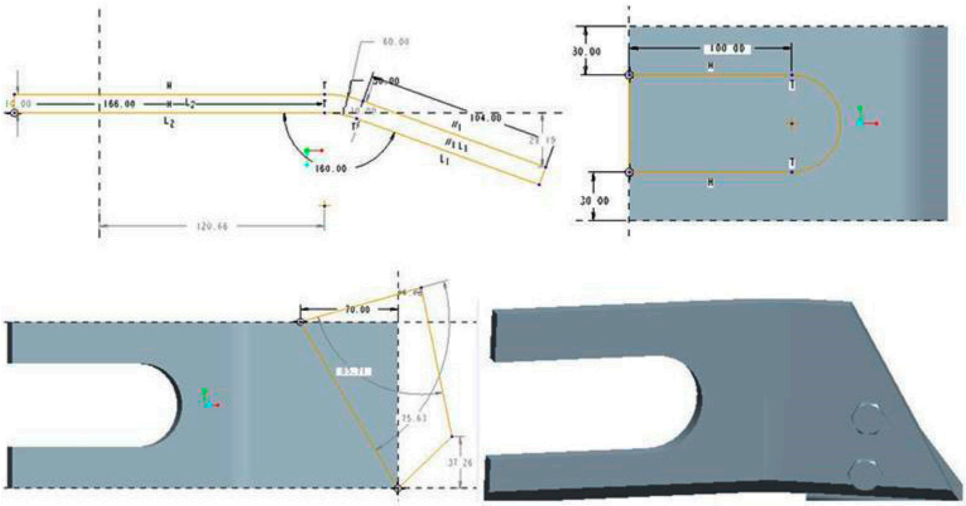

Figure 7. Views and dimensional of Pro/E solid model.

Slots in trash-board support bracket (B) provide ample adjustment. Set trash-board (A) as high as possible, making sure the front point remains against the shin. This allows the trash-board to turn trash quicker and provide a lighter draft. If more trash coverage is desired, lower the rear of the trash, remove the retainer nuts from plow bolts (C), or attach a supporting bracket (B) using existing hardware. The implement, was conceived for cutting, shredding, and frogmen of soil within the moldboard plow. The implement was primarily comprised of three overlapping parts (Figure 8). All three parts will set the trash-board as high as possible, making sure the front point remains against the shin.

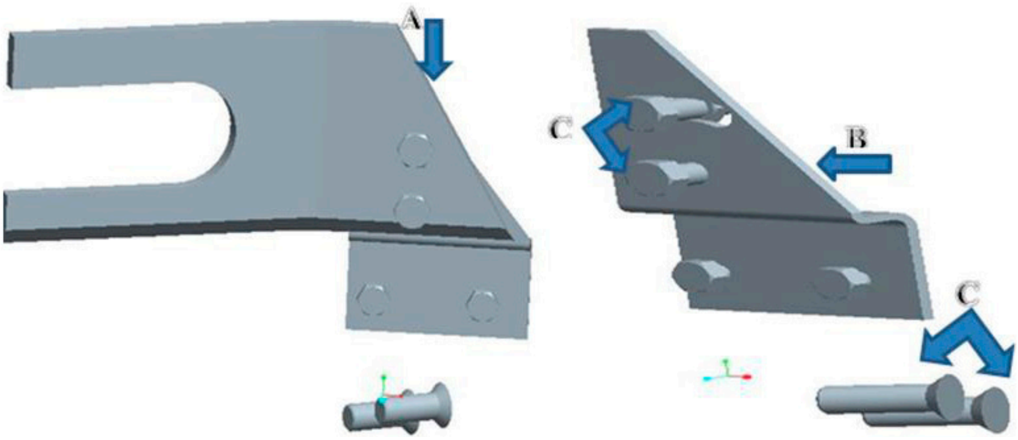

Figure 8. Trash-board parts: (**A**) trash-board; (**B**) support bracket; (**C**) plow bolts.

4.4. Experiment Layout

The main parameters controlled in the field plowing test include forward speed and tillage depth. The complete factorial experimental design relating to two straw conditions and a moldboard plow with and without a trash-board attachment led to four treatments: a plow with a trash-board in stubble condition (WTNS), a plow without a trash-board in stubble condition (WTONS), a plow with a trash-board in dense straw cover (WTHS) and a plow without a trash-board in dense straw cover (WTOHS). Combined with three working depths, the total experimental layouts contained 12 combinations.

4.5. Measurements

Before starting the experiment, standing and flat residue were collected separately, as stubble height treatments alter the ratio of flat to standing stubble. At the time of experiments, two sensors were installed to measure reaction forces and soil samples for gravimetric soil water content. Measurements were randomly taken in each plot at the depths of 0 to 50 mm, 50 to 100 mm, and 100 to 150 mm. The determination method was the same as that used by [6]. Therefore, straw pieces originally situated in the central area were easily distinguished after tillage [25]. A 1-m^2 quadrat was randomly placed on the surface of each plot at three random locations. The flat straw contained within the quadrat was placed before running, and straw unburied was collected first and placed into a paper bag, and the remaining standing straw was measured to determine the average straw brail. Combined with three working depths, total experimental layouts contained 12 combinations. Each treatment was replicated 3 times, leading to 36 testing plots. Each treatment was done within a plot in a size of 3 m $\times$ 10 m. Nine aluminum cubes of 1 cm^3 were used as tracers for soil movement. The tracers were arranged in lines perpendicular to the direction of tool travel. These cubes were labeled and inserted into the soil, and the top surfaces were leveled with soil surface to trace soil movement. Clod sizes were measured with a ruler directly after plowing test. Every clod was numbered and marked in its center for ease of handling.

4.6. Field Testing Platform

The platform for field experiment was designed and constructed in the department of Agricultural Mechanization, College of Engineering, Nanjing Agricultural University [12,25]. The platform was equipped with motion mechanisms and a traction power unit. During the field operation for each tillage treatment, the tractor was operated at the same forwarding speed [13]. Tractor-DT910 tow-wheel-drives 11 kW is equipped to measure engine speed (rpm) in addition to the load cell, consisting of several modules.

4.7. Statistical Analysis

This research was planned as the randomized complete block design (RCBD) with three replications. Soil forces of the moldboard plow in different working conditions, soil water content, a used trash-board, straw movement, and depths were analyzed by SPSS (version 16, SPSS, Inc., Chicago, IL, USA) with ANOVA.

5. Conclusions

Stubble water content is approximately 1.8 times greater than the average stem water content. Our research results agree with previous statements that longer straw had larger displacement at different water content levels. Measured straw displacement had large variances, which were the main reason for the withdrawal of straw. The findings were as follows.

1. The draft was generally the highest without a trash-board and lowest when attaching a trash-board, and only the straw stem had high water content.
2. Draft requirement decreased with the installation of a trash-board and increased water content. The trash-board was also closely related to soil cohesion derived from vane shear measurements.
3. The trash-board has the largest effect for soil fragmentation at different water content levels, but this may be attributed to the benefit of a trash-board, as shown in the result.

4. Both straw length and soil water content impact straw displacement. Thus, it is recommended for farm operators that a trash-board be used with more than 30% water content according to the percentage of straw to be displaced.
5. The results indicate that straw nearby shear significantly increased the displacement for all treatments, at variance of that nearby moldboard.
6. The present study introduced new experimental methods, which will facilitate research in this area.
7. Displacement of soil by moldboard plowing is a severe land degradation process for hilly agricultural land. Reduced soil displacement with a trash-board attachment was also found in other soil conditions, both in bare soil and with standing stubbles. Similar effects of reduced soil displacement were also true for working depths.
8. It is better to set a trash-board as high as possible, making sure the front point remains against the shin. This allows the trash-board to turn trash quicker and provide a lighter draft.
9. If more trash coverage is desired, then the rear of the trash-board should be lowered; (a) remove and retain nuts from plow bolts, and (b) attach the supporting bracket using existing hardware.

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