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Application of Symmetric Ploughs for Tillage on Wetland Paddy Fields

Mas Ade Moetangad Kramadibrata[1], Wahyu Kristian Sugandi[1], Asep Yusuf[1] and Dwi Rustam Kendarto[2]

1. Lab of Agricultural Machinery and Equipment, Dept of Agriculture and Biosystem Engineering, the Faculty of Agro-Industrial Technology, the University of Padjadjaran, Bandung 40600, Indonesia

2. Lab of Soil and Water Engineering, Dept of Agriculture and Biosystem Engineering, the Faculty of Agro-Industrial Technology, the University of Padjadjaran, Bandung 40600, Indonesia

Abstract: Impertinent uses of moldboard plows for tillage on wetland paddy soils, as far more than a century, caused damage to its important hardpan layer of 20-30 cm soil depth that led to some extent, the decrease of rice production than it should have been. The current study has been carried out to repair that damage to regain the "lost" of paddy yields by using the designed flat-symmetric plow that has a lift angle of 29°-30°. It is towed by a hand tractor of 12 horsepower (HP) at a travel speed of 1.11 m/s and a working depth of 10 cm in three blocks of a wetland paddy field in Bandung Sub-district of West-Java, Indonesia. Test results observed from the formed plow sole of 10-15 cm depth underneath after 3rd-time operations of the plow on the same track, indicated that there was a relatively small decrease of moisture content (MC) around 0.182%, as well as increases of cone index (CI) and bulk density (BD) around 0.172% and 0.171%, respectively. This plow was able to maintain, generate and stimulate the formation of hardpan right underneath the plow path. It was due to the improvement of hardpan physical-mechanical properties and would be more significant after frequent tillage using that plow. Hence, there is a chance to develop a tillage method in the development of an ideal wetland paddy cultivation system throughout Indonesian wetland paddy fields.

Key words: Symmetric-flat plow, hardpan, ideal wetland paddy cultivation.

1. Introduction

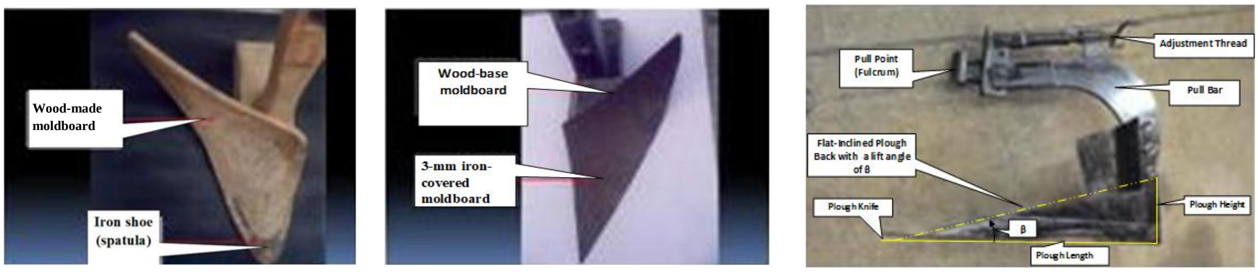
Soil tillage by cutting, slicing, breaking and reversing soils using asymmetric ploughs or the so-called moldboard plough has been mainly used to till dry land, such as dry land European-American soils. In contrast, the symmetric ploughs used to till wetland, especially the Asian wetland soils. Both ways of cultivations defined as Euro-American dryland culture and Asian wetland cultures, respectively [1].

The utilization of the asymmetric plough has appropriately applied on dryland soils, while the symmetric one is specifically on wetland soils. The first plough generates a landside pressure effect and effectively ables to slice, cut and invert the soil. Then, throw it asymmetrically aside the plough, to the right-hand side or the left-hand side so that the soil fractioned into smaller soil particles.

In contrast, the second plough, the so-called symmetric plough, slices and lifts the sliced soil along the plough's flat back and continues to push down to the end part of the plough dump it on behind the plough symmetrically. These plough works generate bottom-side pressure under the plough tread so that there is compacting of the soil layer below it and forms the formation of a somewhat soil more hard and compact, which is called "hardpan" [2].

This hardpan is an integral part of the rice field structure, which lies under the mud of paddy soils, but its existence has to destroy from the dryland because it can inhibit plant root growth since it causes water stagnation in the root zone that disturb plant growth. Reversely, in wetland, especially rice fields, a hardpan

Corresponding author: Mas Ade Moetangad Kramadibrata, professor, Ph.D., research field: agriculture engineering.



(a) Lanyam—a wood moldboard plough with an iron-layered end (spatula) for breaking through soils [5]

(b) Brujul—a wood moldboard plough with its moldboard front-side covered by a 3-mm plate-iron layer [5]

(c) A designed symmetric plough with a lift angle of 13° [6]

Fig. 1 Moldboard plough (traditional) used in West Java, Indonesia: (a) Lanyam; (b) Brujul; (c) symmetric plough.

must exist, form, and even has to remain, for it is an essential part of the paddy soil structure that ensures its productivity better.

Nishimura [3] stated that wetland paddy culture that grows in the mud at a depth of 15 cm up to 20 cm above the hardpan could produce more rice yield than that grows in the mud at a depth deeper than 20 cm or more. As this plough also often used for tillage on wetland paddy, there are some efforts to modify the dryland plough to suit adapting the physical-mechanical soil condition, especially for tillage on wetland paddy soils. It leads to an effort to obtain the result as stated above. The symmetric plough has a better performance than an asymmetric one for tillage on wetland paddy fields due to its ability to form the desired hardpan layer.

The working concept of a moldboard plough is due to its geometric structure (Figs. 1a and 1b) to produce landside pressure that causes hardpan's damage [4, 5]. In contrast, the asymmetric one constructs the hardpan forms and even repairs the damage and improves it due to its flat-symmetric form (Fig. 1c) that could produce the so-called bottom-side pressure compact the soil layer underneath the plough sole [6].

Hence, there is a need to observe the actual performance of this symmetric plough (Fig. 1c) in tillage on wetland paddy fields whether its application could repair and improve the quality of the hardpan as well as its productivity [7, 8].

2. Materials and Methods

2.1 Wetland Rice Field Preparation

Soil samples taken from the 15-cm soil depth of the three blocks of a wetland paddy field prepared for plough testing primarily to investigate its actual physical-mechanical properties.

The sampling has taken before any plough operations based on randomized block design's analysis concerning the soil moisture content (MC), soil density, soil texture, soil type and the cone index (CI).

Laboratorium results showed that each of the properties observed has relatively similar characteristics at an accurate level of 95% (p = 0.05), as shown in Table 1 [6].

2.2 Device Related to Field Tests

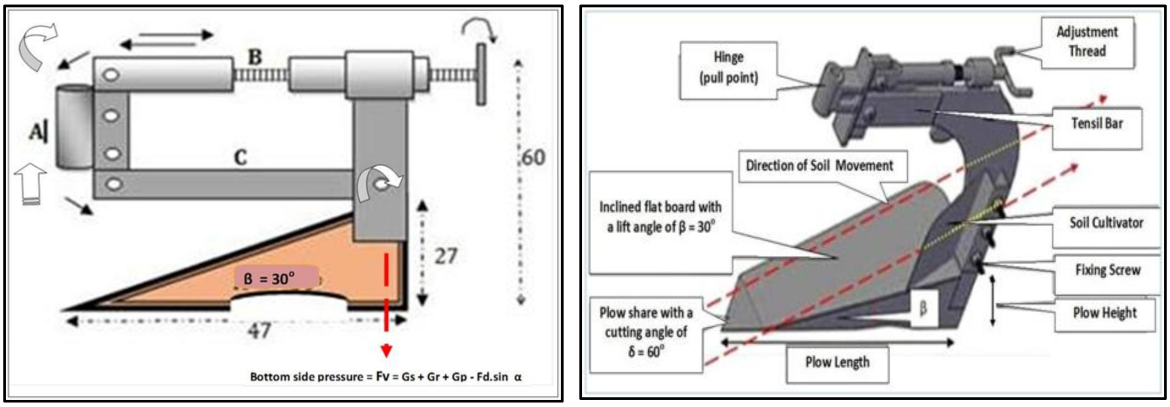
The devices apply, namely, a hand tractor with cage wheels of 6.8 horsepower (HP) capacity, a pull dynamometer with a capacity of 5 t, a display monitor for data readings, a weighing indicator with a display and a flat-symmetric plough.

The flat-symmetric plough wrapped in a 3-mm thin steel plate in the form of a prism with an inclined flat angle (lift angle of β = 30°), which enables it to raise and carry the sliced piece of soil cuts and lets it drop down in its original place at the back of the plough (Fig. 2a). Simultaneously, the plough's front end forms a sharp cutting knife at a cutting angle of δ = 60°

Table 1 Actual physical-mechanical soil condition of the plough sole at Katapang wetland paddy fields.

Soil parameter	Block A	Block B	Block C	Average[b]
Moisture content (MC, % dw)	55.49	52.96	49.47	52.64
Bulk density (BD, g/cm^3)	0.856	0.874	0.898	0.876
Average cone index (CI, N/cm^2)[a]	41.67	39.34	33.78	38.26
Soil texture:				
-Sand fraction (S, %)	14.52	13.77	15.56	14.62
-Ash fraction (Si, %)	42.25	43.35	41.40	42.33
-Clay fraction (C, %)	43.23	42.88	43.04	43.05
Soil type (based on plasticity chart)	siC[c]	siC[c]	siC[c]	siC[c]

[a] averaged from 20-30 cm depth; [b] coefficient of correlation more than 95%; [c] silty clay soil [6].



(a) Front sight (b) Pictorial sight

Fig. 2 A prototype of a designed symmetric plough with a lift angle of *β* = 30° (inproportional dimension: ploughh length = 47 cm; plough height = 27 cm; total height = 60 cm).

(Fig. 2b) with a plough end around 12 cm that acts like a knife of the plough [6-8].

2.3 Method Related to Operational Test

The plough pulled by a tractor of 6.8 HP power size at a constant operating speed and at an effective depth of 4 km/h and 10 cm, respectively. A calibrated load cell of a 5-ton capacity setting up between the drawbar hitch point where the pulled plough's load point utilized as a data reading display monitor of the actual soil draft resistance.

Changes in soil physical-mechanical properties before and after traffics showed in fraction relative to the former conditions. As seen in Fig. 3, the plough pulled by hand tractor from its pull point with a pull force F (towed force) at a pulling angle of α, while the soil was cut-off from its original position by the ploughshare. The cut soil carried over along the inclined plane of the plough at its lift angle of β (13°) until it falls behind the plough right on its former position [7, 8].

In-situ data readings on display were obtained from each plough trajectory one at a time, both in the one up to seven times the traffic, respectively. Based on statistical analysis, plough traffic of 1-3 times traffics had significant effects relative to the initial soil condition. There were no significant differences from the fourth traffics as also obtained on dryland [7, 8]. Therefore, data readings from 4-7 tracks discarded.

Data of the soil draft resistance obtained from numbers of loads are at the pull point's dynamometer. These data used to gain the magnitude of loads projected to the plough bottom. This so-called bottom side pressure compacted the soil underneath the plough path, which became denser than the former

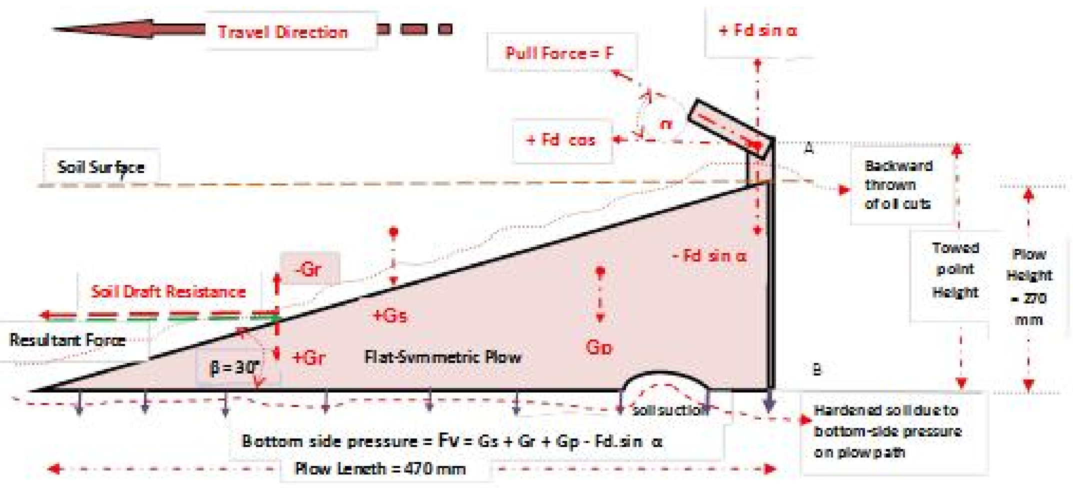


Fig. 3 The free-body diagram of the bottom side pressure (*Fv*).

density during plough operations.

The magnitude of the compaction was a characteristical change in the physical-mechanical properties of the plough path that is reflected by the changes in soil MC, bulk density (BD) and CI from the condition before and after traffic successively by the plough at one up to seven times of traffics.

Changes in soil physical-mechanical properties before and after traffics showed infraction relative to the former conditions. The plough towed by hand tractor from its pull point with a towed force F at a towing angle of α. The soil was cut off from its original position by the ploughshare. The cut soil was carried over along the inclined plane at its lift angle of β = 30° until it falls behind the plough right on its original position. As shown in Fig. 3, some of the forces projected onto the x-axis (horizontal) and the z-axis (vertical), where:

(1) The pulled force F projected onto the x-axis as a horizontally resultant force ($+Fd*\sin\alpha$). This force experiences soil resistance opposite to the horizontal forces' direction, the so-called soil draft resistance ($-Fd*\sin\alpha$);

(2) The pulled force F parallel with the z-axis as a vertical upward force ($+Fd*\sin\alpha$) but effective as a downward force opposite the bottom-side pressure ($-Fd*\sin a$);

(3) Downwards vertical forces resulted from the weights of the plough (Gp) and the soil (Gs) that occurred when the plough pulled horizontally through the ground ($+Gp$ and $+Gs$).

Hence, there is a total pressure force downward that sums all pressures resulted from the plough movement, that is,

$$Fd*\sin\alpha + Fd*\cos\alpha*\sin\beta + G*90°*\sin\beta \quad (1)$$

where β is the lift angle of 30°, G is the plough's dynamic weight and the soil on the plough's inclined plane, and any other additional loads that can compress on the ground.

Referring to Figs. 2 and 3, the following describes soil draft resistance (Fd), which is a soil reaction against the plough action that is moved horizontally through into the soil. So,

$$Fd = F*\cos\alpha \quad (2)$$

(a) Fd is the force exerted by the plough that is moved perpendicularly toward the plough operation as operated at a constant speed. The value of Fd can be summed or directly measured and read on the display monitor.

(b) Fd generates a resultant force opposite and parallel to the plough operation direction as the plough penetrates the soil. Simultaneously, it produces an action force upwards ($-Gr$) and downwards ($+Gr$), whereas the cut soil lifts and moves through along over the inclined surface of the plough at a lift angle of β = 30°. It falls back behind the plough.

(c) Static force resulted from the soil's dynamic weight above the plough (+*Gs*) that acts vertically downwards.

(d) Static forces resulted from the plough weight itself (+*Gp*) acts vertically downwards.

All those forces become a total pressure vertically downwards to the plough sole, which presses and compact the soil layer underneath, resulting in the so-called bottom-side pressure (*Fv*), which sum up as:

$$Fv = Gs + Gr + Gp + Fd^{*}\cos\alpha + Gr/\tan\beta - Fd^{*}\sin\alpha \quad (3)$$

where *Gs* are the force of the soil weight that pressed down the plough, *Gr* being the plough weight, and *Gp* being the coefficient of friction between the plough and the incremental loads due to the plough's operation speed.

3. Results and Discussion

3.1 Physical-Mechanical Changes of the Plough Sole

Changes in the physical-mechanical properties of lowland soil were observed under the plough tread at a depth of 10-15 cm before and after the symmetric plough was operated across the plough track 1-7 times, each repeated three times in the paddy field. The parameters observed included soil moisture, soil density and CI.

The observations' results are listed in Table 2 which shows that the soil's physical-mechanical parameters have changed significantly from the initial state (before traffic), especially after crossing 1-3 times on the same path. However, there are no significant changes from the fourth up to the seventh traffic and beyond. This phenomenon similarly occurred as has been found in dryland [9, 10].

The test results were not significant at the confidence level p = 0.05. It is proof of the treatment that the formation of hard soil layer can gradually develop into hardpan structures that are occurring as the effect of the bottom side pressure on the plough tread.

3.2 Bottom-Side Pressure

Bottom-side pressure (*Fv*) resulted from the plough obtained from incorporating Eq. (3) by considering plough and soil parameters such as plough weight, coefficient of friction between plough and soil, rolling resistance of the towing tractor, the volume of dislocated soil mass. *Fd* measured by the dynamometer, in which data detected at a constant operating speed of the symmetric plough showed.

The average value of *Fv* read in the display was 191-196 N/cm^2. The value was almost close to the result value calculated, i.e., 184-185 N/cm^2 [7, 8].

3.3 CI Stratigraphy before and after Plough Traffics

The effect of the symmetric plough application of various lift angles of the ploughs on the wetland paddy field's soil structure indicated by the soil profile's CI stratigraphy [7, 8], as shown in Fig. 4.

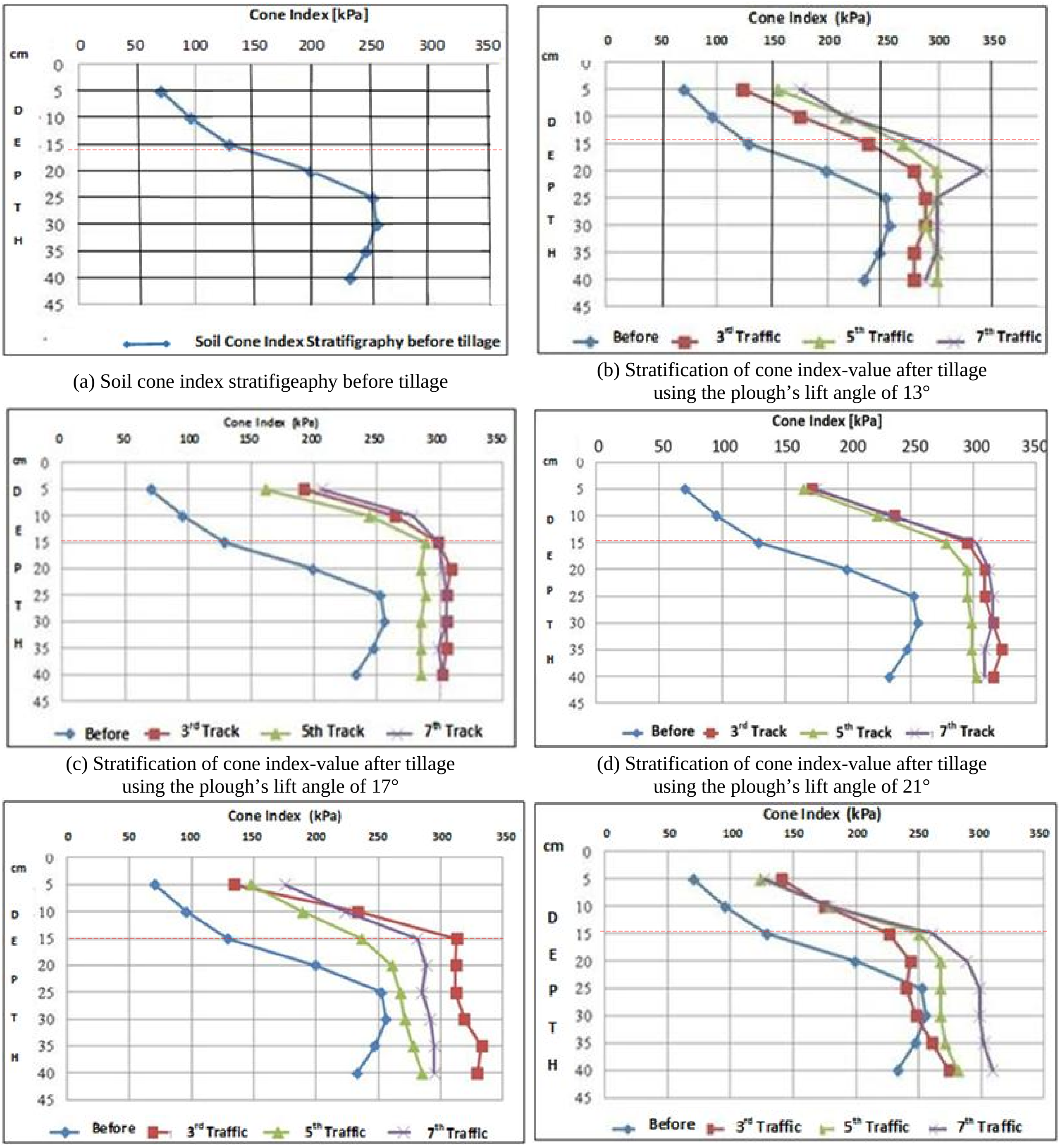
Table 2 Fractional changes of soil's physical-mechanical conditions of plough sole at 10-15 cm depth profile of Katapang wetland paddy fields before and after traffics.

MC (% dw)	BD (g/cm^3)	CI (N/cm^2)	MC decrease (%)	BD increase (%)	CI increase (%)	Result
Before traffic						
52.64	0.876	41.67	0.00	0.00	0.00	Initial
After the first traffic						
52.56^a	0.889^a	90.56^a	-0.124^a	+0.129^a	+0.128^a	Significantly different*
After the second traffic						
52.51^b	0.897^b	130.00^b	-0.163^b	+0.164^b	+0.165^b	Significantly different*
After the third traffic						
52.47^c	0.901^c	153.33^c	-0.182^c	+0.172^c	+0.171^c	Significantly different*

Table 2 to be continued.

MC (% dw)	BD (g/cm³)	CI (N/cm²)	MC decrease (%)	BD increase (%)	CI increase (%)	Result
After the fourth to the seventh traffic						
52.46[c]	0.901[c]	156.24[c]	-0.183[c]	+0.178[C]	+0.182[c]	Not significantly different**

*the same letter = not significantly different; **the different letters = significantly different.



(a) Soil cone index stratifigeaphy before tillage

(b) Stratification of cone index-value after tillage using the plough's lift angle of 13°

(c) Stratification of cone index-value after tillage using the plough's lift angle of 17°

(d) Stratification of cone index-value after tillage using the plough's lift angle of 21°

(e) Stratification of cone index-value after tillage using the plough's lift angle of 25°

(f) Stratification of cone index-value after tillage using the plough's lift angle of 30°

Fig. 4 Effect of the symmetric plows of various lift angles on cone index stratigraphy in the wetland paddy field.

The broken lines in Figs. 4a-4f indicated that the pressure's compaction effect occurred due to the plough trajectory downward to the 15-cm depth and beyond. Its effects might reach down to the soil layer far more profound than 15 cm.

The CI stratigraphy (Fig. 4) indicated curves of "after the traffic" has shifted each to the right side from "before the traffic". Their CI values were significantly different. Those values started from the third up to the fifth trackings and beyond have disregarded. The field facts showed almost similar phenomena as the test result indicated in the dryland condition [9, 10].

(1) This is the desired hardpan depth to retain water or to inhibit percolation rate in the drought season or to release excessive water in the rainy season to the ground water. Thus, the hardpan would act as water detention or water supply at the appropriate planting season.

(2) The limit mud depth of max 15 cm is an ideal growing medium for the roots of rice seeds/plants, and it would produce optimal rice productivity, because:

(a) Rice stalks are a long, knotted paddy plant pipe that is continuous from the rice roots to the surface of the water and is connected to the outside air so that air/oxygen can easily reach the roots, where the respiration process occurs in the mitochondria of the root cells. Here, occurs the so-called Kreb cycle, which processes energy by absorbing oxygen (O_2) for biochemical processes as well as removing carbon dioxide (CO_2), and the process continues over and over. Thus rice plants would grow and earn their yields.

(b) Hardpan position of 15 cm below the mud is the desired depth limit because the mud profile is only 15 cm and becomes an ideal growing medium for rice plant growth. These occurred due to the distance between the roots of rice plants, and the hardpan's surface is close so that the plant roots ease to gain access to absorb nutrients deposited and accumulated over there as well as have the base to grow and develop in a relatively solid ground (hardpan).

4. Conclusions

The report discussed herewith is an initial part of 2-3 years of planned research related to field problems due to impertinent uses of moldboard (asymmetric) ploughs instead of using the symmetric ploughs tillage on wetland paddy fields.

It showed that the symmetric plough could generate and form the hardpan on wetland paddy fields as indicated by the changes of the hardpan's physical-mechanical properties caused by bottom-side pressure exerted from the respective plough.

It highlighted by the significant diminutive changes of soil MC, BD and CI on the hardpan top layer after one, three, five and seven times ploughing, i.e., by the plough with the lift angle $\beta = 13^o, 17^o, 21^o, 25^o$ and 30^o. The changes indicated a positive correlation between the respective symmetric plough traffics to the formation of hardpan structure in wetland paddy fields. Further observations under a similar condition on the same wetland paddy field using the plough with the various lift angles of β seem to highlight similar characteristics.

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References

[1] Sakai, J. 1998. "Cultural Difference of Tillage Science and Technology between Euro-American Upland Wheat Farming and Asian Lowland Paddy Rice Farming." Presented at the Annual Seminar of Indonesian Society of Agriculture Engineers (PERTETA), University of Padjadjaran, Bandung, Jatinangor.

[2] Kramadibrata, A. M. 2014. "Specific Soil Draft Resistance of Some Moldboard Ploughs Performed in Wetland Paddy Soil." Presented at International Conference on Sustainable Food and Agricultural Security, Bandung.

[3] Nishimura, I. 1992. *Several Problems in the Farm Mechanization*. Research report, Japan International Corporation Agency-Department of General High Education, Agriculture University Bogor, Project-92a(132), Bogor.

[4] Kramadibrata, A. M. 2000. "Performnce Analysis of Some Geometric Structures of Moldboard Ploughs for Tillage on Wetland Paddy Fields." Dissertation, Post-graduate Program, Agriculture University, Bogor.

[5] Meilita, N., and Kramadibrata, A. M. 2009. *Study on Characteristical Relationships of Physical-mechanical Mud of Wetland Paddy Fields and the Productivity of Paddy Plants (Oriza sativa L.)*. Research report, Dept of Agricultural and Biosystem Engineering, Faculty of Agro-Industrial Technology, University of Padjadjaran, Bandung, 94. (in Indonesian)

[6] Kramadibrata, A. M. 2016. "Dynamic Performance of a Symmetric Plough for Tillage on Wetland Paddy Fields Using the 13^{o} Lift-Angle of a Flat-Symmetric Plough." Presented at International Conference on Appropriate Technology and Development, Intititute of Knowledge Science, LIPI Serpong, Indonesia.

[7] Apriliyani, A. N. 2018. *Analysis of Physical-Mechanical Changes of the Hardpan in Cultivating Wetland Paddy Fields Using the 13° Lift-Angle of a Flat-Symmetric Plough.* Research report, Dept of Agricultural and Biosystem Engineering, Faculty of Agro-Industrial Technology, University of Padjadjaran, Bandung, 98. (in Indonesian)

[8] Wahidah, R., and Kramadibrata, A. M. 2019. *Geometric Structure Modification of Flat-Symmetric Plows towards the Formation of an Ideal Wetland Paddy Fields*. Research report, Dept. of Agricultural and Biosystem Engineering, Faculty of Agro-Industrial Technology, University of Padjadjaran, Bandung, 104. (in Indonesian)

[9] Taylor, J. H., Burt, E. C., and Bailey, A. C. 1980. "Effect of Total Load on Subsurface Soil Compaction." *Transaction of the ASAE* 23: 568-70.

[10] Taylor, J. H., Burt, E. C., and Bailey, A. C. 1982. "Multipass Behaviour of a Pneumatic Tire in Tilled Soils." *Transaction of the ASAE* 1229-31, 1236.

Appendix

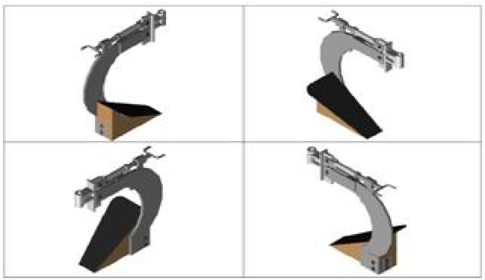

Fig. 1 Pictorial sights of a symmetric plough type.

Fig. 2 The symmetric plough of 30° tilt angle at large.

Fig. 3 Setting up the symmetric plough on a handtractor.

Fig. 4 Plow operation & hardpan formation at 10-cm depth.