SUGARCANE PRODUCTIVITY AS A FUNCTION OF SOIL MECHANICAL MANIPULATIONS[1]

(*Produktivitas Tebu Sebagai Fungsi Dari Manipulasi Mekanik Tanah*)

Gatot Pramuhadi[2]

ABSTRACT

Sugarcane production was a function of plant, growing media (soil), climate, and human activity. Climate was a factor that could not be changed, whereas plant and soil could be changed or manipulated by human activity. Dry land sugarcane cultivation was done mechanically that beginning from soil tillage, planting, plant maintenance, and up to harvesting activities. Soil tillage was a soil mechanical manipulation in order to reach a proper environment for plant growing. On dry land sugarcane cultivation, it was conventionally consisting of subsoiling, plowing, harrowing, and furrowing. Treatments can be done by applying the intensities of plowing and harrowing to acquire variation of soil physical conditions. Optimum soil tillage method was determined by best soil physical condition, which it produced maximum sugarcane growth and productivity. The objective of the research was to analyse the effect of soil mechanical manipulations toward sugarcane growth and productivity. The research was conducted on dry land sugarcane plantation area at Gula Putih Mataram Company on September 2002 until August 2003. Six-soil tillage methods were applied and sugarcane seedlings (variety of TC-9) were planted, and then soil physical conditions, tractors' performance, and sugarcane growth and productivity were measured and calculated. Results of the research showed that sugarcane growth and productivity were varied by the actions of soil mechanical manipulation. The soil mechanical manipulation with minimum intensities produced optimum soil physical condition that resulted in maximum sugarcane growth and productivity. Soil tillage method of subsoiling – moldboard plowing – disk harrowing – furrowing was an optimum soil mechanical manipulation activity that produced maximum sugarcane productivity of 63.1 ton/ha.

Key words: *soil mechanical manipulation, soil physical condition, productivity, optimum, and maximum.*

[1] Disampaikan dalam Gelar Teknologi dan Seminar Nasional Teknik Pertanian 2008 di Jurusan Teknik Pertanian Fakultas Teknologi Pertanian UGM, Yogyakarta 18-19 November 2008

[2] Department of Agricultural Engineering, Faculty of Agricultural Technology, IPB

A. INTRODUCTION

1. Background

Sugarcane production was a function of plant, growing media (soil), climate, and human activity. Climate was a factor that could not be changed, whereas plant and soil could be changed or manipulated by human activity. Maximum sugarcane production was achieved if the four factors, as above, were in optimum conditions.

Plant genetic factor that commonly influenced sugarcane production was genotype or variety. The usage of superior variety would result in high sugarcane growth and production.

Soil contributed as a media for sugarcane stalk upright and roots growth, and together with water contributed as a media for roots' nutrient absorption. Maximum sugarcane growth and production were achieved if soil in optimum condition.

Climate was a factor that influenced the availability of sunlight, air, and water. It contributed as a media for sugarcane to adapt and grow up to harvest.

Human activities were a factor that contributed for sugarcane best growing in order to acquire a high sugarcane production. It was achieved by applying cultivation engineering that beginning from soil tillage, planting, and plant maintenance up to harvesting activities.

Soil tillage was the first activity, where its energy usage was the biggest, because it required big power to till soil. Its effectiveness and efficiency determined quality of the next cultivation result until harvesting activity.

Soil tillage was a soil mechanical manipulation in order to reach a proper environment for plant growing. On dry land sugarcane cultivation, it was conventionally consisting of subsoiling, plowing, harrowing, and furrowing. Treatments can be done by applying the intensities of plowing and harrowing to acquire the variation of soil physical conditions. Optimum soil tillage method was determined by best soil physical conditions, which it produced maximum sugarcane growth and productivity.

Soil tillage in dry land sugarcane cultivation area was mechanically conducted by means of four-wheel tractors. The tractors must had sufficient available power because when it were applied to till soil so that almost overall available power was used, thus it was very important to measure and calculate it's magnitude of fuel consumption and power.

2. **Objective**

The objective of the research was to analyse the effect of soil mechanical manipulations toward sugarcane growth and productivity.

B. MATERIALS AND METHOD

1. **Time and Place**

The research was conducted on September 2002 until August 2003 in a dry land sugarcane area at Gula Putih Mataram Company, Sugar Group Company, Central Lampung.

2. **Variables**

Main research variables which be used to analyse the effect of soil mechanical manipulations toward sugarcane growth and productivity are:

a. Soil dry bulk density (S_{BD})
b. Fuel consumption (V_{FC} and W_{FC})
c. Sampling sugarcane productivity (P_{TS})
d. Sampling sugar productivity (P_{GS}).

3. **Machines, tools, instruments, and materials**

Machines, tools, instruments, and materials consisted of:

Two units of four-wheel tractor:

a. FIAT (Fiatagri-New Holland 4WD type, 140 hp, 7140 kg) and JOHN DEERE (JD6250-4WD type, 100 hp, 3950 kg)
b. Soil tillage tools:
   A subsoiler plow (straight shank, 2 bottoms, 0.30 m depth), a disk plow (standard, 3 disks, 0.64 m disk diameter), a moldboard plow (long moldboard, 2 bottoms, 1.66 m width), a disk harrow (two-gangs heavy duty, 28 cutaway disks, 4.32 m width), and a furrower (adjustable wings, 3 bottoms, 4.00 m width)
c. Instruments:
   Some metal rings (EIJKELKAMP), a stopwatch, a measuring tape, a vernier caliper, a measuring glass, a thermometer, an analytical balance, an oven, a desicator, and a waterbath

d. Materials:

Sugarcane seedlings (variety of TC-9), diesel fuel, and water.

4. Method

A schematic diagram of the research design can be shown in **Figure 1**. Six soil tillage methods were applied in a dry land sugarcane area of ± (450 m x 180 m) = ± 8 ha, as shown in Figure 2. Tractor Fiat was used to pull subsoiler plow, disk harrow, and furrower, whereas tractor John Deere was used to pull disk plow and moldboard plow.

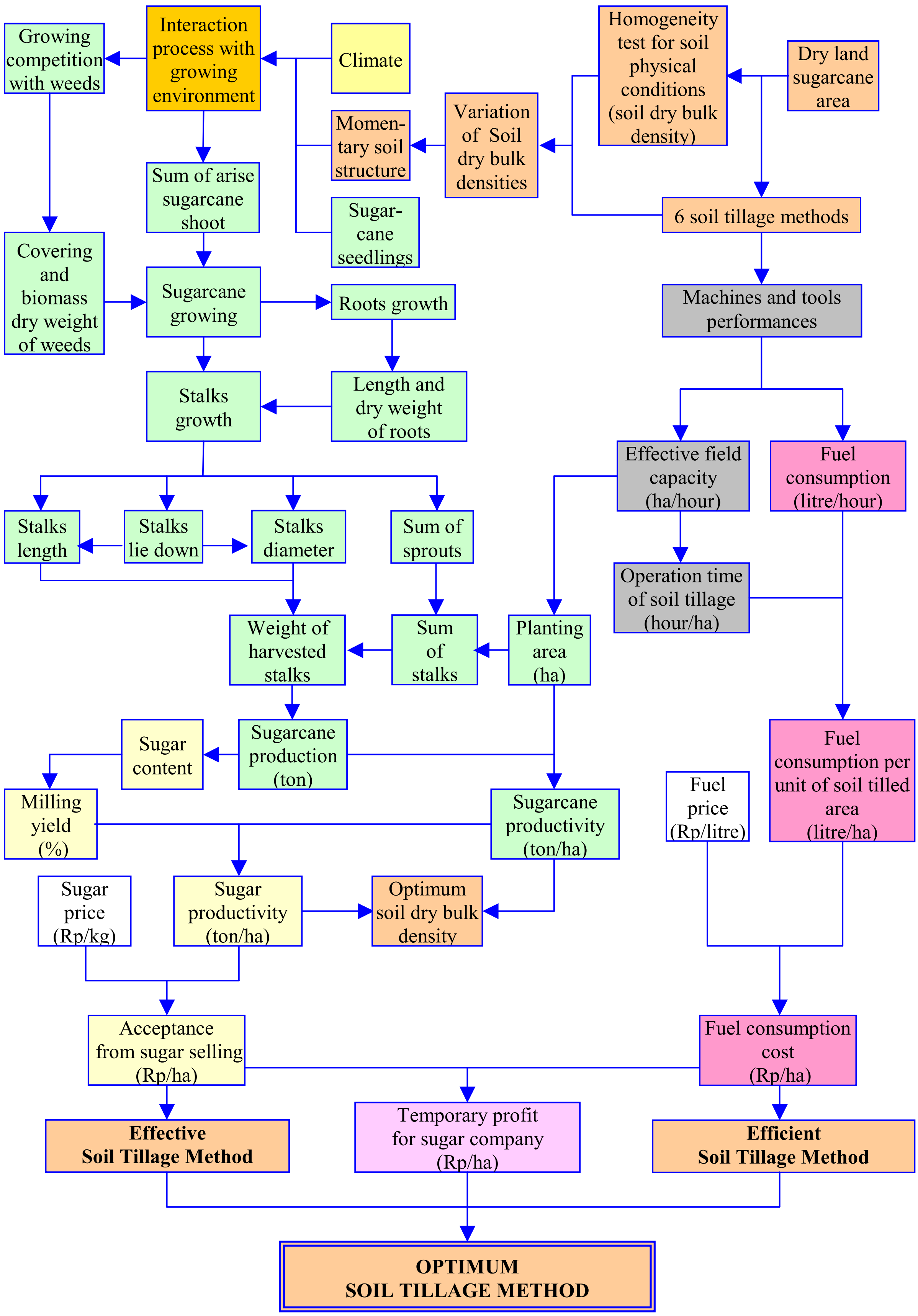
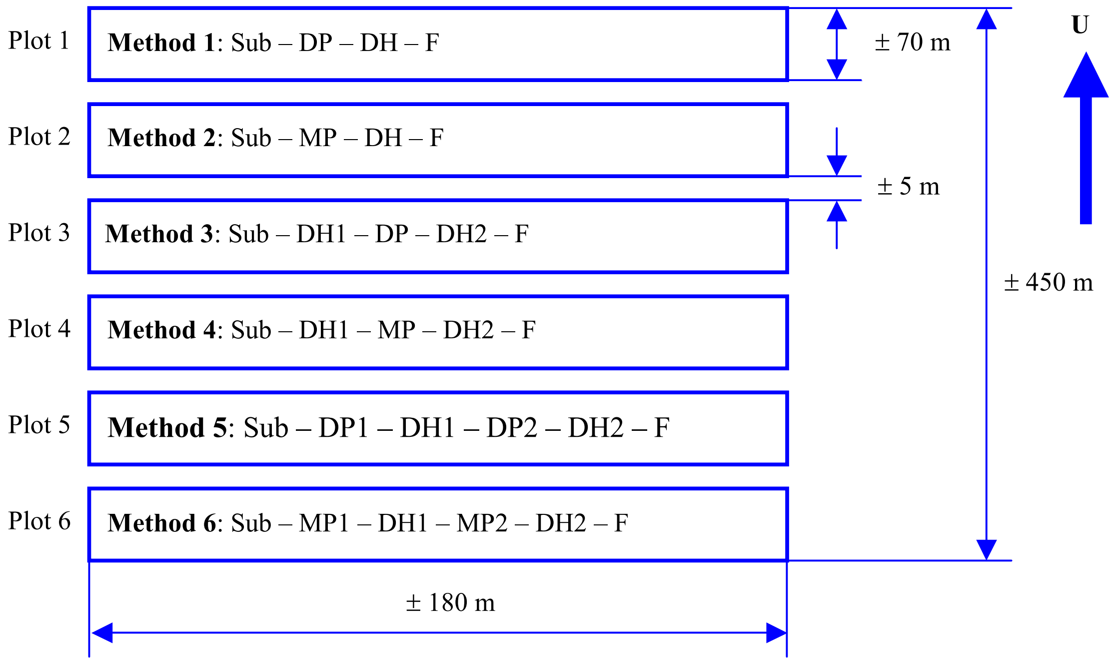


Figure 1. A schematic diagram of the research design to analyse the effect of soil mechanical manipulations toward sugarcane growth and productivity



Sub = Subsoiling (deep soil tilling utilizes subsoiler plow)
DP = Disk Plowing (soil tilling utilizes disk plow)
MP = Moldboard Plowing (soil tilling utilizes moldboard plow)
DH = Disk Harrowing (soil tilling utilizes disk harrow)
F = Furrowing (soil tilling utilizes furrower)

Figure 2. Plots allocation of six soil tillage methods

On each application of soil tillage method, volume of fuel consumption (V_{FC}), fuel temperature (T_F), and soil dry bulk density (S_{BD}) were measured. The data were used to calculate variables, such as fuel density (D_F), weight of fuel consumption (W_{FC}), tractor power (P_T), and specific fuel consumption (S_{FC}). Sampling sugarcane productivity (P_{TS}) and sampling sugar productivity (P_{GS}) were measured and calculated before harvesting. Formulas or equations to calculate the variables were written in equation 1 up to equation 11.

Growth variables were measured during the growing period, or it was similar 9 months. The variables were sum of arise shoots (J_{TM}), roots length (P_{AT}), stalk tall (T_{BT}), stalk diameter (D_{BT}), and sum of sprouts (J_{AT}).

Effectiveness of soil mechanical manipulation was valued according to amount of acceptance from sugar selling (A_{SS}), whereas efficiency of soil mechanical manipulation was valued according to fuel consumption cost (F_{CC}). A difference between A_{SS} and F_{CC} was a temporary profit for sugar company (P_{SC}). Optimum soil mechanical manipulation was obtained if the application of soil tillage method was effective and efficient, and optimum soil dry bulk density was determined according to highest values of P_{TS} and P_{GS}. Optimum soil tillage method was determined according to a highest value of P_{SC}.

$D_F = 0.8402 - 0.0007 * T_F$ ......(1)

$W_{FC} = V_{FC} * D_F$ ......(2)

$E_F = 48998 + 2392.1 * D_F - 13078 * D_F ^ 2$ ......(3)

$E_{FC} = E_F * W_{FC}$ ......(4)

$P_F = E_{FC} / (1.055 * 2545 * T / 3600)$ ......(5)

$P_T = 0.33 * P_F$ ......(6)

$S_{FC} = W_{FC} / (P_T * T / 3600)$ ......(7)

$S_{FC} = V_{FC} / (P_T * T / 3600)$ ......(8)

$P_{TS} = 10 * T_{BS} / (P_{JS} * J_{AR})$ ......(9)

$R_{GT} = Pol - 0.4 * (Brix - Pol) * (W_N / W_T)$ ......(10)

$P_{GS} = P_{TS} * R_{GT}$ ......(11)

Where:

D_F	=	diesel fuel density, kg/litr
T_F	=	fuel temperature, ºC
W_{FC}	=	weight of fuel consumption, kg
V_{FC}	=	volume of fuel consumption, litre
E_F	=	average of heat value of diesel fuel, kJ/kg
E_{FC}	=	energy of fuel consumption, kJ
P_F	=	power value of fuel, hp
1.055	=	conversion factor (1 Btu = 1.055 kJ)
2545	=	conversion factor (1 hp.hour = 2545 Btu)
P_T	=	mechanical power of tractor, brake hp
0.33	=	maximum heat efficiency of diesel fuel for diesel engine Jones, 1952)
S_{FC}	=	specific fuel consumption, kg/hp.hour, litre/hp.hour
P_{TS}	=	sampling sugarcane productivity, ton/ha
10	=	conversion factor (1 kg/m^2 = 10 ton/ha)
T_{BS}	=	total weight of sampling sugarcane stalks, kg
P_{JS}	=	sampling length, m
J_{AR}	=	distance between planting rows, m

R_{GT}	=	milling yield, %
Pol	=	sugar content in liquid sap from sugarcane stalks
Brix	=	sugar and non-sugar contents in liquid sap from sugarcane stalks
W_N	=	weight of liquid sap from sugarcane stalks, kg
W_T	=	weight of milled sugarcane stalks, kg
P_{GS}	=	sampling sugar productivity, ton/ha

C. RESULTS AND DISCUSSION

Soil in the dry land sugarcane area is Ultisol (*Podsolik Merah Kuning*). Soil texture from surface up to 0.60 m depth is sandy clay and sandy clay loam. Based on homogeneity test by using Bartlett method showed that soil physical characteristic (soil dry bulk density) before soil tilling is homogeneous, that is 1.44 g/cc in average, so that its effect to the machines operation is uniform.

When the six-soil tillage methods are applied, it shall formed soil physical condition with a certain value of soil dry bulk density and the tractors shall consume fuel with certain fuel consumption, it influences sugarcane growth and productivity, and it determines temporary profit for sugar company. The results are presented on **Table 1, Table 2, Table 3,** and **Table 4.**

Results of the research showed that soil dry bulk density, fuel consumption, and tractor power vary that are caused by soil mechanical manipulation activities. The increasing of its intensities caused the increasing of soil dry bulk density, total field time, fuel consumption, and tractor power, but it caused the decreasing of sugarcane growth and productivities. It indicates that the results become ineffective and inefficient when its intensities are increased, and it indicates that maximum sugarcane growth and productivity are obtained on minimum soil mechanical manipulation intensities.

The increasing of soil dry bulk density is caused by compaction of machines and tools operation; more intensity caused more compaction, so it caused a higher value of soil dry bulk density. This case obstructed sugarcane growth, so the sampling sugarcane and sugar productivities decrease. The increasing of soil mechanical manipulation intensities requires more power for tractors to till soil, so that the tractors consume more fuel. During the manipulating, the tractors consume a constant specific fuel consumption of 0.19 kg/hp.hour.

Results of the research also showed that maximum sampling sugarcane productivity of 63.08 ton/ha, maximum sampling sugar productivity of 7.30 ton/ha, and maximum temporary profit for sugar company of Rp 34,655,448/ha are obtained on optimum soil dry bulk density of 1.29 g/cc. It indicates that the application of minimum soil mechanical manipulation intensities will results in optimum soil tillage method, that is "subsoiling – moldboard plowing – disk harrowing – furrowing".

Table 1. Performance of the machines and tools operation

Method	Soil mechanical manipulation activities	Symbols and units of variables							
		S_{BD} g/cc	T hour	V_{FC} litre	W_{FC} kg	P_T hp	S_{FC} kg/hp.hour	P_{TS} ton/ha	P_{GS} ton/ha
1	Sub	1.42	0.536	17.00	13.87	134.27	0.19		
	DP	1.28	0.575	8.00	6.53	58.94	0.19		
	DH	1.36	0.708	12.50	10.21	74.86	0.19		
	F	1.31	0.821	19.40	15.81	99.97	0.19		
	Total / ***Average***	***1.31***	**2.640**	**56.90**	**46.42**	**368.04**	***0.19***	***56.15***	***6.71***
2	Sub	1.41	0.536	17.00	13.87	134.27	0.19		
	MP	1.24	0.832	11.40	9.29	58.05	0.19		
	DH	1.34	0.710	14.00	11.40	83.36	0.19		
	F	1.29	0.794	22.70	18.42	120.69	0.19		
	Total / ***Average***	***1.29***	**2.872**	**65.10**	**52.98**	**396.37**	***0.19***	***63.08***	***7.30***
3	Sub	1.43	0.536	17.00	13.87	134.27	0.19		
	DH 1	1.40	0.543	9.40	7.66	73.33	0.19		
	DP	1.32	0.557	10.30	8.41	78.38	0.19		
	DH 2	1.32	0.736	13.00	10.61	74.89	0.19		
	F	1.35	0.727	17.10	13.99	99.83	0.19		
	Total / ***Average***	***1.35***	**3.099**	**66.80**	**54.54**	**460.70**	***0.19***	***41.54***	***5.09***
4	Sub	1.39	0.536	17.00	13.87	134.27	0.19		
	DH 1	1.42	0.578	8.40	6.85	61.53	0.19		
	MP	1.35	0.608	7.00	5.72	48.82	0.19		
	DH 2	1.37	0.630	13.60	11.08	91.32	0.19		
	F	1.38	0.713	19.70	16.08	117.07	0.19		
	Total / ***Average***	***1.38***	**3.065**	**65.70**	**53.60**	**453.01**	***0.19***	***45.64***	***5.84***
5	Sub	1.35	0.536	17.00	13.87	134.27	0.19		
	DP 1	1.34	0.566	12.40	10.09	92.68	0.19		
	DH 1	1.32	0.597	16.00	13.01	113.18	0.19		
	DP 2	1.31	0.583	13.30	10.84	96.61	0.19		
	DH 2	1.31	0.562	12.00	9.81	90.63	0.19		

	F	1.36	0.730	24.00	19.52	139.00	0.19		
	Total / ***Average***	***1.36***	**3.574**	**94.70**	**77.14**	**666.37**	***0.19***	***40.77***	***5.96***
6	Sub	1.36	0.536	17.00	13.87	134.27	0.19		
	MP 1	1.31	0.804	12.35	10.04	64.95	0.19		
	DH 1	1.34	0.649	9.30	7.56	60.59	0.19		
	MP 2	1.22	0.753	11.55	9.41	64.92	0.19		
	DH 2	1.28	0.566	14.00	11.42	104.88	0.19		
	F	1.31	0.715	15.10	12.34	89.60	0.19		
	Total / ***Average***	***1.31***	**4.023**	**79.30**	**64.64**	**519.21**	***0.19***	***36.41***	***3.94***

Sub = subsoiling, DP = disk plowing, MP = moldboard plowing, DH = disk harrowing, F = furrowing, S_{BD} = soil dry bulk density, T = total field time, V_{FC} = volume of fuel consumption, W_{FC} = weight of fuel consumption, P_T = tractor power, S_{FC} = specific fuel consumption, P_{TS} = sampling sugarcane productivity, and P_{GS} = sampling sugar productivity

Table 2. Sugarcane growth and productivities based on soil tillage methods

Research Variables	Unit	Soil Tillage Methods						Ave-rage	Deviation Standard	Coefficient of Variation
		1	**2**	**3**	**4**	**5**	**6**			
S_{BD}	g/cc	1.31	1.29	1.37	1.38	1.36	1.30	1.34	0.04	0.03
J_{TM}	shoot/m^2	8.67	11.33	8.33	12.67	5.67	6.33	8.83	2.74	0.31
P_{AT}	cm	22.15	21.99	21.86	20.35	18.85	22.55	21.29	1.41	0.07
T_{BT}	cm	112.28	108.34	105.39	116.86	106.58	112.95	110.40	4.38	0.04
D_{BT}	mm	21.69	20.82	20.67	20.80	20.43	20.81	20.87	0.43	0.02
J_{AT}	stalk/bunch	1.83	2.56	1.61	2.14	1.64	1.78	1.93	0.36	0.19
P_{TS}	ton/ha	56.15	63.08	41.54	45.64	40.77	36.41	47.27	10.24	0.22
R_{GT}	%	11.95	11.57	12.25	12.80	14.62	10.82	12.34	1.30	0.11
P_{GS}	ton/ha	6.71	7.30	5.09	5.84	5.96	3.94	5.81	1.19	0.20

S_{BD} = soil dry bulk density, J_{TM} = sum of arise shoots, P_{AT} = roots length, T_{BT} = stalk tall, D_{BT} = stalk diameter, J_{AT} = sum of sprouts, P_{GT} = weeds covering, B_{BG} = dry weight of weeds biomass, P_{TS} = sampling sugarcane productivity, R_{GT} = milling yield, and P_{GS} = sampling sugar productivity

Table 3. Sugarcane growth and productivities based on soil tillage intensities

Research Variables	Unit	Soil Tillage Intensities			Average	Deviation Standard	Coefficient of Variation
		4 times	5 times	6 times			
S_{BD}	g/cc	1.30	1.38	1.33	1.34	0.04	0.03
J_{TM}	shoot/m^2	10.00	10.50	6.00	8.83	2.47	0.28
P_{AT}	cm	22.07	21.11	20.70	21.29	0.70	0.03
T_{BT}	cm	110.31	111.13	109.77	110.40	0.68	0.01
D_{BT}	mm	21.26	20.74	20.62	20.87	0.34	0.02
J_{AT}	stalk/bunch	2.20	1.88	1.71	1.93	0.25	0.13
P_{TS}	ton/ha	59.62	43.59	38.59	47.27	10.98	0.23
R_{GT}	%	11.76	12.53	12.72	12.34	0.51	0.04
P_{GS}	ton/ha	7.01	5.47	4.95	5.81	1.07	0.18

S_{BD} = soil dry bulk density, J_{TM} = sum of arise shoots, P_{AT} = roots length, T_{BT} = stalk tall, D_{BT} = stalk diameter, J_{AT} = sum of sprouts, P_{GT} = weeds covering, B_{BG} = dry weight of weeds biomass, P_{TS} = sampling sugarcane productivity, R_{GT} = milling yield, and P_{GS} = sampling sugar productivity

Table 4. Calculation results for determining optimum soil tillage method

Soil Tillage Methods	T_{OP} (hour/ha)	F_{CA} (l/ha)	P_{GS} (ton/ha)	F_{CC} [1)] (Rp/ha)	A_{SS} [2)] (Rp/ha)	P_{SC} (Rp/ha)	Optimum Sequence
1	3.86	73.44	6.71	308 448	32 208 000	31 899 552	No. 2
2	4.93	91.56	7.30	384 552	35 040 000	34 655 448	No. 1
3	4.19	87.94	5.09	369 348	24 432 000	24 062 652	No. 5
4	4.27	78.27	5.84	328 734	28 032 000	27 703 266	No. 4
5	5.99	148.05	5.96	621 810	28 608 000	27 986 190	No. 3
6	7.39	131.06	3.94	550 452	18 912 000	18 361 548	No. 6

T_{OP} = total operation time, F_{CA} = total fuel consumption per unit area, P_{GS} = sampling sugar productivity, F_{CC} = fuel consumption cost, A_{SS} = acceptance from sugar selling, and P_{SC} = temporary profit for sugar company

1) Calculated with fuel price of Rp 4200/litre at that time in year of 2003

2) Calculated with sugar price of Rp 4800/kg at that time in year of 2003

D. CONCLUSION

1. The increasing of soil mechanical manipulation intensity causes the increasing of soil dry bulk density, tractor power, and fuel consumption, and causes the decreasing of sugarcane growth and productivity, so that results in ineffective and inefficient soil mechanical manipulation
2. The application of minimum soil mechanical manipulation intensity produces an optimum soil dry bulk density that results in maximum sampling sugarcane and sugar productivities, and maximum temporary profit for sugar company
3. Soil tillage method of "subsoiling – moldboard plowing – disk harrowing – furrowing" is an optimum soil mechanical manipulation activities on dry land sugarcane cultivation on Ultisol soil at Central Lampung, Indonesia

E. RECOMMENDATION

1. The research method will preferable if it can be applied to other places with different soil type
2. The usage of renewable energy, such as bio-diesel, can be considered to convert diesel fuel usage, although several problems may occur when bio-diesel fuel is used for soil tilling, so we must not to ignore its compatibility with diesel fuel and tractor's engine adaptation and adjustment

REFERENCES

Jones, Fred R. 1952. *Farm Gas Engines and Tractors*. Third Edition. McGraw-Hill Book Company, Inc. New York, U.S.A.

Pramuhadi, G. 2005. *Pengolahan Tanah Optimum pada Budidaya Tebu Lahan Kering* (Optimum Soil Tillage on Dry Land Sugarcane Cultivation). Dissertation. Postgraduate School, Institut Pertanian Bogor