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EFFECTS OF TILLAGE METHODS AND DEPTH ON FUEL CONSUMPTION AND PROFITABILITY OF LATE SEASON OKRA PRODUCTIONS

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A b s t r a c t. The disc plough and disc harrow were used singly and in combination to produce seedbeds of depths 10, 15, 20, and 25 cm for late season okra (*Abelmuscus esculentus*) production. During the seedbed preparation, the time used for tilling and the fuel consumed were used to calculate the tillage energy as well as the specific power requirement. Using the different tillage methods, the cost of seedbed preparation was estimated for the various tillage depths. Yield from the plots and the benefits accruing from the sale of harvested okra fruits were used to compare the tillage methods at the different tillage depths.

Total cost, fuel consumption, time of operation, fuel and tillage energies increased with tillage depth and were higher for combined tillage operations than the single ones. Specific power requirement decreased with increased tillage depth and was not statistically different in any tillage method. Yield and economic profitability were higher for the combined tillage operations but were varied between tillage depths. Harrowing once after ploughing at 15 and 20 cm depths were the most profitable tillage method and depths for late season okra production.

K e y w o r d s: *Abelmuscus esculentus*, fuel consumption, okra, profitability, tillage method and depth

INTRODUCTION

The main purpose of tillage in agriculture is to provide seedbeds with adequate moisture, aeration and soil strength for optimum crop establishment, growth and yield. Its importance can be evaluated by the size of the cultivated area, the time, energy and cost it requires, the effect it has on yield and the profitability of the system, as well as efficient conservation of resources and energy use [12]. The choice of the tillage method for any seedbed preparation should be based on its cost effectiveness, i.e., lowest cost and less power-consuming tillage processes [7,18]. Different tillage methods are employed in the cultivation of crops throughout the world. Crop yields were known to have been substantially increased using improved seedbeds. The manipulation of soil by using suitable tillage tools to secure a good environment for seed germination and plant growth is the oldest branch of arable agriculture. In the Nigerian traditional agriculture, we plough and harrow once most of the time but for difficult soils we harrow twice after ploughing. This combination of tillage tools (plough, harrow, and/or ridger, etc) to produce the required seedbed for plant growth is usually refered to as "combined" tillage. But, because ploughing remains still one of the most energy-consuming operations in arable farming [4], it has been suggested that energy consumption be used as a criteria for evaluating tillage methods [8]. Soil tillage represents a problem of mounting concern nowadays because of its energy costs and agronomic implications including its impact on crop production [16]. The systematic increases in the cost of fuel, spares and machinery and the present depressed economy have made the excessive use of machinery prohibitive [23]. Tillage is the most costly operation in the budget of a farmer because amongst all agricultural operations tillage machinery requires a tremendous amount of power for adequate seedbed preparation.

Research on the possibility of reducing tillage number and depth in Nigeria has continued [2,14,15,20,21], because depth of tillage has considerable influence on the power requirements and performance of tillage tools. An increase in the depth of tillage, other conditions being constant, increases the power requirement [5,9,19,27]. Scepanovic *et al.* [22] reported that reduced and rational soil tillage provide quality seedbed preparation as well as significant savings in fuel, manpower and machines. The amount of fuel and the time used by a specific tractor as indices for comparing energy requirements of a particular tillage operation are influenced by soil physical properties, type and condition of tillage implement and speed of operation [6]. Thus, the energy input in seedbed preparation through tillage, even though it does not control plant growth directly, governs the flow of water and air to roots, may have an effect on the quality of the seedbed, the soil fertility, the activity of microorganisms and thus on the growth and development of okra crop and finally on fruit yields. Since tillage involves costs, the choice of tillage method determines the profitability of okra fruit production. Any tillage practice which merely changes soil condition and does not produce required results should be eliminated or changed. The soil needs to be prepared only enough to ensure optimum crop production and weed control. As such there is potential benefit in reducing energy cost. However, the primary objective of any cropping program is continued profitable production.

This paper reports on an experiment which may enable farmers choose the right cost-effective tillage method and depth for profitable late-season okra production. The study had the following specific objectives:

1. To compare the different tillage practices commonly used by okra farmers in terms of yield, energy requirement (fuel consumption) and profitability to the farmer.

2. To identify any justification for tillage methods outside the conventional (P+H) for late season okra production.

MATERIALS AND METHODS

The experiment was conducted for four years on a sandy loam Ultisol at the Mbato Substation of the National Horticultural Research Institute (NIHORT), Okigwe (05^o 3'N and 07^o 23'E at 130 m a.s.l). Soil samples were taken from 10 random points at each of 5-10,10-15, 15-20 and 20-25 cm depths from each plot using 100 cm^3 metal core. The soil physical and chemical properties were analyzed in the laboratory using standard techniques and presented in Table 1. Soil moisture values before the commencement of tillage and at one and three weeks after tillage (Table 2) were obtained by the standard oven drying method and averaged.

Table 1. Physical and chemical properties of the Mbato sandy loam Ultisol*

Parameters (%, W/W)	Depth (cm)		
	0 - 10	10 - 20	20 - 30
Coarse Sand	18	70	23
Fine Sand	50	46	44
Silt	20	19	17
Clay	12	15	16
Plastic limit	21.6	23.2	24.1
Liquid limit	36.9	38.2	39.5
Organic carbon, C	1.61	1.02	0.43
Nitrogen, N	0.31	0.22	0.08
Available P (mg/kg)	4.92	3.03	1.12
pH	5.6	5.3	5.8

* Average of four years.

The implements used for the tillage operation include a FIAT 780 tractor with a rated engine power of 77 hp at 2500 rpm, a 3-disc (diam. 71 cm and disc angle 20^o) plough of working width and depth 100 cm and 28 cm, respectively and weighing 600 kg and an off-set disc harrow (diam. 51cm, 20 discs spaced at 23 cm centres) of working width 200 cm and weighing 595 kg. The working depth of the harrow was 18 cm.

The tillage treatments include (1) Ploughing only (P), (2) Harrowing only (H), (3) Ploughing followed by once harrowing (P+H), and (4) Ploughing followed by twice harrowing (P+2H), consisting of three runs each of 50 m long at full working widths and at plough tillage depths d = 10, 15, 20 and 25 cm achieved using

Table 2. Soil moisture variation with depth (%)

Tillage depth (cm)	Before tillage	Plough only (P)	Harrow only (H)	Plough+once harrow (P+H)	Plough+twice harrow (P+2H)
		One week after tillage			
10	12.5	10.9±0.26	11.0±0.26	11.3±0.15	11.3±0.20
15	14.8	12.3±0.06	12.1±0.16	11.8±0.08	12.5±0.32
20	15.1	13.5±0.10	13.5±0.09	13.9±0.13	12.9±0.15
25	15.4	14.1±0.15	14.0±0.11	14.5±0.06	14.3±0.18
		Three weeks after tillage			
10		11.1±0.08	11.4±0.12	11.8±0.06	11.6±0.05
15		12.9±0.15	11.9±0.15	13.4±0.14	12.1±0.12
20		13.8±0.13	12.8±0.07	18.2±0.11	14.4±0.09
25		14.7±0.07	14.1±0.13	16.0±0.0	15.2±0.16

the tractor's depth control. All tillage treatments were performed on straight rows by the same operator at tractor engine speed of 1850 rpm and mean forward speed of 3.75 km/h. A no-till control was not used in this study because it is not a conventional practice in vegetable production in Nigeria.

The total time (T, h/ha) of each operation measured using a stop watch included actual productive time and time used for turning, momentary breakdown, etc. [24]. Fuel consumption was measured using the topping method in which the fuel tank of the tractor was completely filled up with diesel fuel (density D = 0.82 kg/l and heat value H=42.5 MJ/kg) before starting each tillage operation. After tilling the desired area of the plot, the tank was refilled using a fuel measuring glass tube. The amount of fuel required to refill the tank is equal to the amount of fuel consumed (Q) by the tractor for the tillage operation [1,11,17]. The fuel consumption (FC) was defined for this work as the fuel consumed per unit area tilled (l/ha) and given by:

$$FC=Q/W\ L,\ \ l/ha \qquad (1)$$

where L, W - length and width of tilled area (m), respectively. The total time and fuel consumed are given in Table 3. The fuel energy (FE), tillage energy (TE) and specific power requirement (SPR) for seedbed preparation were calculated (Table 4) using the following equations:

$$FE=FC\ \ D\ \ H,\ \ J/ha \qquad (2)$$

Table 3. Fuel consumption and time for each operation

Tillage depth (cm)	P	H	P+H	P+2H
		Fuel consumption (l/ha)		
10	10.0±1.2	6.3±0.9	18.6±1.6	27.6±2.1
15	13.5±0.9	7.2±0.5	21.9±0.8	31.8±2.8
20	15.9±1.6	8.4±0.3	25.7±0.9	35.2±1.9
25	18.3±1.3	9.5±0.6	28.5±1.8	39.8±2.3
		Time for each operation (h/ha)*		
10	2.55±0.06	1.40±0.02	4.31±0.09	5.88±0.11
15	3.20±0.09	1.68±0.06	5.18±0.10	6.96±0.24
20	3.80±0.10	1.99±0.03	6.29±0.12	8.05±0.39
25	4.43±0.07	2.28±0.05	7.15±0.08	9.57±0.26

* Average of four years.

Table 4. Fuel energy, tillage energy, specific power requirement

Tillage depth (cm)	P	H	P+H	P+2H
		Fuel energy (MJ/ha)*		
10	383.4±26.5	219.6±24.9	468.2±41.2	961.9±66.4
15	470.5±35.1	250.9±21.8	763.2±30.9	1108.2±81.5
20	554.1±18.2	292.7±32.1	895.6±85.3	1226.7±49.6
25	637.8±20.9	331.1±25.3	993.2±49.6	1387.0±57.1
		Tillage energy (MJ/ha)*		
10	49.7±6.9	28.5±3.4	48.0±8.1	124.7±9.6
15	61.0±2.5	32.5±3.8	98.9±6.9	143.6±7.5
20	71.8±3.8	37.9±2.1	116.1±7.5	158.9±4.9
25	82.7±4.1	42.9±2.6	128.7±4.6	179.8±6.8
		Specific power requirement (kW/m$^{3)}$		
10	54.10±3.2	56.50±8.1	54.10±3.6	58.90±2.9
15	35.33±6.9	35.80±9.2	35.33±6.4	38.20±4.3
20	26.25±4.8	26.45±9.6	25.65±3.1	27.40±3.7
25	20.76±2.5	20.92±7.5	20.00±4.3	20.88±4.6

*Average of four years.

$$TE=e_1\, e_2\, e_3\, FE, \quad J/ha \tag{3}$$

$$SPR+TE/d\, T, \quad kW/m^3 \tag{4}$$

where e_1 - traction efficiency (0.6), e_2 -transmission efficiency (0.9), e_3 - engine efficiency (0.24) taken from Matthews [18].

The test crop okra (*Abelmuschus esculentus*) is of the *Malvaceae* family containing 2% protein, vitamin A (0.2 mg/100 g), vitamin C (25 mg/100 g) and calcium (92 mg/100 g) and whose preparation can be used as a blood plasma replacement [28]. The cultivar NHlae 47-4 used in this work, introduced by NIHORT, is early maturing (about 6 weeks), green in colour, ridged and has short and pointed stout fruits measuring 2-5 cm long and 3-4 cm in diameter. The dry seeds were hand-planted at a spacing of 75x20 cm in-between and within rows, respectively. At three weeks after planting, N:P:K: 15:15:15 fertilizer was supplied at the rate of 175 kg/ha to the plots after hoe -weeding. They were applied in rings of 10 cm diameter around each plant. Prophylactic spraying of sevin and dithane at standard doses of 1.5 and 2.5 a:i in 100 l of water, respectively were carried out every two weeks and gave good control of insects and fungal attack, respectively. The total yield of okra fruits from twelve 3-day harvests/plot starting 45 days after planting was used to determine the yield response to tillage treatments.

The quantities of fertilizer, chemicals and seeds used for post-seedbed preparations were the same for all plots. Prevailing market prices were used to cost them. Costs for labour and hiring of tillage tools and tractor were at prevailing rates. Combined with fuel costs, these fixed/variable cost parameters (Table 5) were used to determine the costs (N/ha) of each treatment using the procedure by Hunt [10].

RESULTS AND DISCUSSION

Soil properties

The sandy loam Ultisol used in this study had its liquid and plastic limits increasing with depth (Table 1). Soil moisture content also increased with depth (Table 2) for all tillage methods. One week after tillage, each treatment combination (method + depth) recorded lower soil moisture because of evaporation from fairly bare soil and seedling emergence.

P and H treatments conserved more moisture than P+H and P+2H because they had larger clods with lesser soil surface area. $(P+H)_{15}$ conserved more moisture later in the growing season because it produced larger leaves that may have provided more cover,

Table 5. Cost of seedbed (N/ha) preparation and other cultural practices

Items	Tillage depth (cm)	P	H	P+H	P+2H
Fuel and oil	10	890	540	1580	2090
	15	1020	760	1990	2760
	20	1260	970	2350	3470
	25	1510	1190	2870	3660
Tractor/equipment hire		1700	1500	2000	2000
Labour Costs (operator and attendant)	10	410	560	680	710
	15	490	600	780	820
	20	570	690	820	900
	25	600	810	890	940
Post seedbed cultural practices		1200	1200	1200	1200
Materials (seed)		600	600	600	600
Fertilizer		1800	1800	1800	1800
Chemicals		1600	1600	1600	1600

*Average of four years (N82=1 USC).

reducing evaporation and conserving moisture. The P+2H treatment enhanced internal soil drainage and decreased soil moisture content at depths despite the fact that some rain fell a few days before the readings were taken at the 3rd week.

Time and fuel consumption

Time affects costs as well as fuel consumption and energy among other parameters. Both time and fuel consumed increased with depth for all tillage methods but they were least in the H treatment and highest in the P+2H treatment. This trend seems acceptable since all tillage operations were done at constant engine speed. And the working width of H (200 cm) being twice that of P (100 cm) may have made the time and fuel consumed per hectare twice for P than for H (Table 3). Figures 1a and 1b show that there were positive linear relationships of time of operation and fuel consumption with tillage depth [26]. The P+2H treatments consumed about 3.05 - 3.45 times more fuel and more time per hectare than the H treatment at the same depth, while P treatment consumed about 1.75 - 1.94 times more fuel and time than the H treatment. For this particular diesel tractor working on the sandy loam Ultisol at the tillage depths up to 25 cm, the FC, has a highly significant (at 1%) linear relationship with the time consumed per hectare given by:

$$FC=0.091+4.25T \quad (r^2=0.989). \qquad (5)$$

Energy and power input

Using Eqs (1) to (4) above, the FE, TE and SPR per tillage method and depth combination were calculated and presented in Table 4. Both fuel energy and tillage energy increased with tillage depth [9,19] and were least at H_{10} and highest at $(P+2H)_{25}$ as shown in Figs 2a and 2b. Again, there are high positive linear relationships between TE and FE with tillage depth. Addition of once harrowing to the P treatments (P+H) increased mean fuel and tillage energy inputs by 56-69% and adding twice harrowing (P+2H) increased them by 117-151%. These increases arose from the higher fuel consumption over longer times used for the seedbed preparation in the combined tools treatments.

The specific power requirement (SPR) was found to decrease with increase in tillage depth (Fig. 2c) as has been observed by Hendrick and Gill [9]. It is interesting to observe that SPR was nominally least at the (P+H) treatment for all

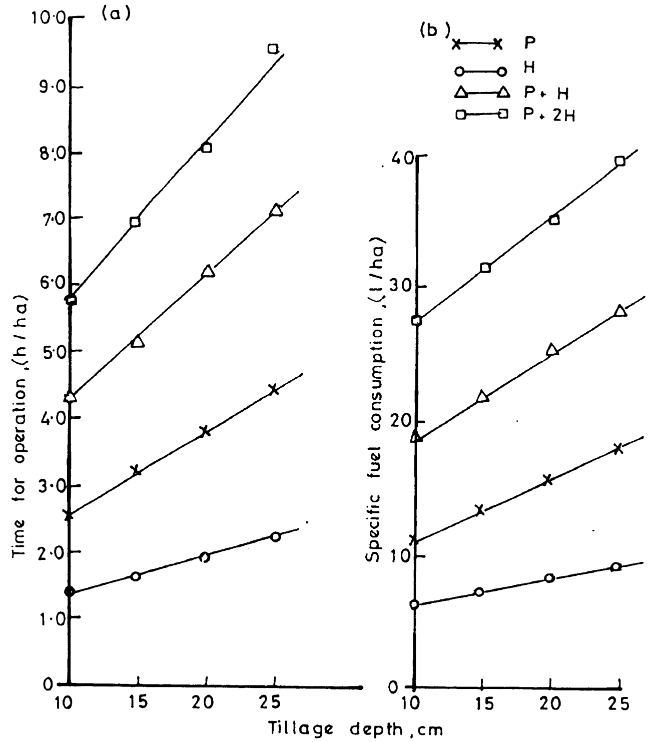

Fig. 1. Effect of tillage depth on time for operation (a) and specific fuel consumption (b) for different tillage methods.

tillage depth, an indication of the beneficial attribute of this tillage method. The higher SPR for the H treatment than for the P treatment may be due to its greater working width since both tools had similar weight. Statistically, there is no significant difference in the value of SPR between tillage methods within each tillage depth. Their values were averaged and presented in Fig. 2c with the linear regression equation given as:

$$\mathrm{Ln(SPR)}=6.263-0.995\ \mathrm{Ln}(X) \quad (r^2=0.883). \quad (6)$$

For the combined tools, SPR was higher for the P+2H treatment than for the P+H due to compaction from the tractor and tool weights during the second and third traffics which would need more fuel for the extra power required to overcome the soil resistance to tillage.

Tillage cost and crop yield

The cost items of the tillage operations are given in Table 5. While fuel, oil and labour costs varied significantly with tillage method and depth, the post seedbed cultural practices, materials and seeds, fertilizer and chemicals, were the same amount for all tillage methods. Tractor and equipment hire costs varied according to tillage tools combinations. The lowest cost was that of the H treatment while the costliest was the P+2H treatment which consumed more time and fuel. When averaged over tillage depth, fuel cost contribution on the total cost of each tillage method was H=10.5%, P= 13.6%, P+H=21.6%, and P+2H=27.6% which were much lower than was observed for difficult-to-manage Vertisols [1].

The combined tools, P+H, and P+2H, utilized higher tillage energy to produce substantially higher yields than the single tools (P and H) for all tillage depths (Table 6). At $(P+H)_{15}$, $(P+H)_{20}$ and $(P+2H)_{10}$, the highest yields 8.16, 8.40, and 8.15 t/ha, respectively were produced. P and H treatments did not produce significantly different yields from each other (<6.0 t/ha) and are unlikely to be generally accepted as tillage

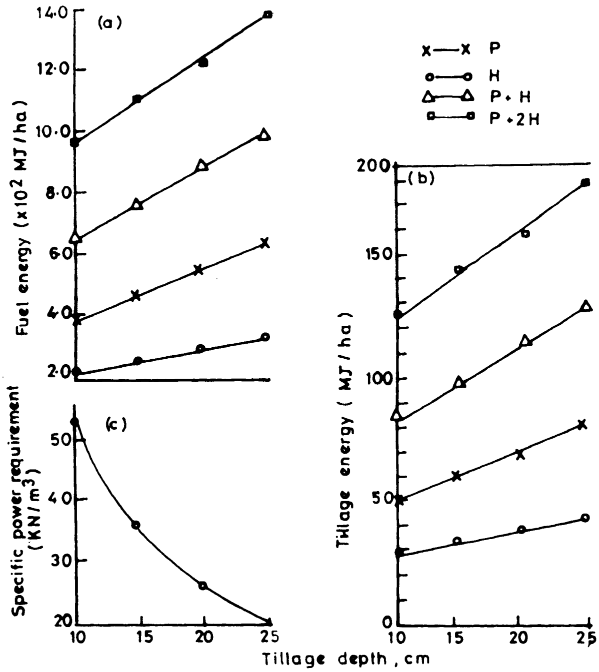

Fig. 2. Effect of tillage depth on fuel energy (a), tillage energy (b) and specific power requirement (c) for different tillage methods.

T a b l e 6. Average yield of okra fruits (t/ha)*

Tillage depth (cm)	P	H	P+H	P+2H
10	5.25±0.11	5.28±0.09	7.50±0.32	8.15±0.14
15	5.40±0.08	5.75±0.12	8.16±0.21	7.85±0.12
20	5.62±0.00	5.89±0.06	8.40±0.19	7.79±0.08
25	5.55±0.08	5.68±0.10	7.95±0.13	7.75±0.13

*Average of four years.

methods for mechanized vegetable farming as they produced large clods [3,7] which hinder post tillage mechanical operations and cultural practices and reduced crop yield. The P+H treatment termed the conventional tillage system, provides a more favourable soil environment (increased soil moisture and more pulverized soil) at the 15 and 20 cm depths for okra production for higher yields and net profit [2]. It is very common in all kinds of cropping system all over the world [13]. The variations of yield with tillage depth for the P+H and P+2H treatments were not of statistical significance (Fig. 3a). The yield obtained in the P+2H method decreased with increase in depth but was substantially higher than yields from single tool treatments.

The total cost was found to have a positive linear relationship with tillage depth for all the tillage methods tested (Fig. 3b). They were significantly higher for the combined tillage operations than for the single ones because of higher energy input. However, since total cost was much higher for the P+2H treatment than for the P+H treatment (Table 7, Fig. 3b), the P+H treatment may then be adjudged as a better multiple tillage operation for okra production.

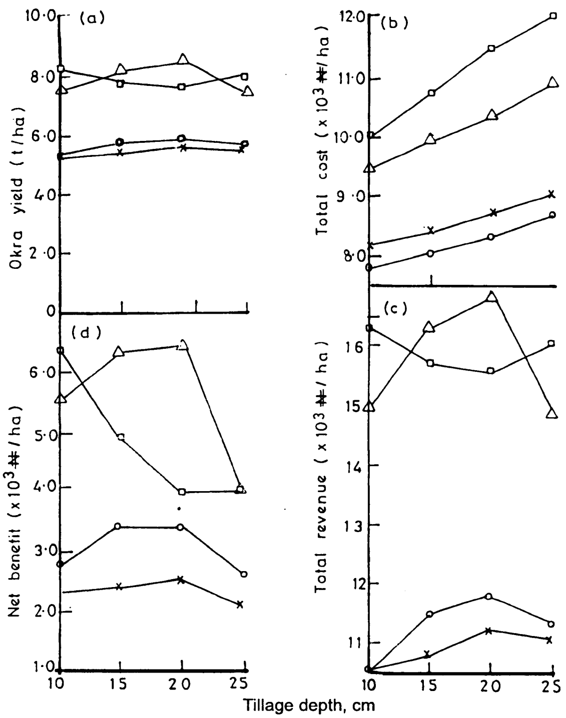

Fig. 3. Effect of tillage depth on okra yield (a), total cost (b), total revenue (c) and net benefit (d) for different tillage methods.

T a b l e 7. Profitability of okra production*

Tillage depth (cm)	P	H	P+H	P+2H
		Total cost (N/ha)		
10	8200	7800	9460	10000
15	8410	8060	9970	10780
20	8730	8360	10370	11570
25	9010	8700	10960	11800
		Total revenue (N/ha)		
10	10500	10560	15000	16300
15	10800	11500	16320	15700
20	11240	11780	16800	15580
25	11100	11360	15900	15500
		Benefit (N/ha)		
10	2300	2760	5340	6300
15	2390	3440	6350	4920
20	2510	3420	6430	4010
25	2090	2660	4940	3700

*Average of four years (N82=1USD).

Profitability of tillage methods

The yields from the single tillage operations positively correlated with tillage energy and specific power requirement at 5% level of significance. With the multiple tillage operations there were no statistically significant yield-energy or specific power relationships. The $(P+H)_{15}$, $(P+H)_{20}$ and $(P+2H)_{10}$ treatments consuming 98.9, 116.1, 124.7MJ/ha of tillage energy produced 8.16, 8.40 and 8.15 t/ha of okra fruits, respectively. The significant differences in tillage energy producing non-significant yields of okra in the P+H and P+2H treatments show that tillage energy input did not affect crop yield directly [25]. What may have affected yield in these treatments is the improved soil conditions produced by the tillage operations. The total revenue accruing from the sale of the fresh okra fruits produced is presented in Fig. 3c and Table 7. It followed the same trend as the yield. Revenue was statistically higher for the combined tillage operations than the single ones. The P+H and P+2H treatments were more costly and consumed more energy (fuel and tillage) to produce higher yields and revenue. Despite the increased establishment costs, the benefit (returns to the farmer) was highest at $(P+H)_{15}$, $(P+H)_{20}$ and $(P+2H)_{10}$ amounting to N6350, N6430 and N6300 per hectare, respectively. At the other multiple tillage operations' depths, it was above N3700/ha. For the P and H treatments revenue ranged from N2090/ha to N3440/ha and were found to be lower than for the combined tillage tools. The highest revenue averaged N6300/ha for the three treatments which consumed tillage energy between 98.9 and 124.7 MJ/ha. Below and above these tillage energies, yield and net profit decreased meaning that there is an optimum tillage energy which would give an optimum net profit to an okra farmer. Again it was observed that total costs and revenue for these three treatments were not statistically different from each other and averaged N10113/ha and N16473/ha, respectively. These three tillage treatments, $(P+H)_{15}$, $(P+H)_{20}$ and $(P+2H)_{10}$ may, in terms of profitability, be recommended to late season okra farmers. This is confirmed by the high negative percentage difference in benefits between P+H and P+2H tillage methods (Table 8). In this study, ploughing followed by once harrowing (conventional tillage) to 15 and 20 cm depth and ploughing followed by twice harrowing to the 10 cm depth were found to give optimum values in terms of all factors monitored. But most importantly these tillage methods at the said depths gave the highest profitability.

Table 8. Differences between P+H and P+2H in percentages*

Tillage depth (cm)	FC (l/ha)	Time of operation (h/ha)	Fuel energy (MJ/ha)	Tillage energy (MJ/ha)	Okra yield (t/ha)	Total cost (N/ha)	Benefit (N/ha)
10	48.4	36.4	48.4	48.4	8.7	5.9	13.7
15	45.2	34.4	45.2	45.2	-3.8	8.1	-22.5
20	37.0	28.0	37.0	37.0	-7.3	11.6	-37.6
25	39.6	33.8	39.6	39.6	6.6	10.4	-3.4

CONCLUSIONS

1.The time for seedbed preparation, the fuel consumed per operation, the tillage energy input and the total cost of production for all the tillage methods tested increased with increase in tillage depth.

2. The P and H treatments consumed less energy and produced the lowest yields and are not recommended for late season okra production in a sandy loam Ultisol.

3. Multiple tillage operations consumed more energy, cost more and produced more yield and net profit.

4. Yields and benefits were highest at the $(P+H)_{15}$, $(P+H)_{20}$ and $(P+2H)_{10}$ treatments and are recommended to late season okra farmers.

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