Predicting Optimum Traction Performance under Different Operating Conditions

AHMED E. GOMAA
Soil and Agricultural Chemistry-(Agricultural Engineering) Dept.
Fac. of Agric., Alex. Univ. Egypt.

ABSTRACT

This study is based on a mathematical simulation and graphing 3-D wireframe maps to detect the variation in traction performance under various engine, loading, and tyre working conditions. Tractive efficiency and fuel consumption are the indicators used in traction performance evaluation. Wireframe map represents the surface of variation of the testing indicator based on selected working conditions. Twenty engine operating points for John Deere 4055 - 110 horsepower tractor, were adopted from the related literature, and used for the purpose of this study. These operating points constitute a feasible range of tractor operating surface from which a corresponding surface of indicators will generate. Traction is applied under a combination of two loading levels; two tyre pressures. At each operating point, traction performance is computed, and indicators are predicted according to the specified working conditions. The outputs of all points form the required surfaces of variation. The comparison is then made between the operating points on the same surface and on different surfaces to select optimum conditions.

ADDITIONAL INDEX WORDS: traction, tyre, engine, load, efficiency.

INTRODUCTION

After the 73 oil embargo, reducing fossil fuel requirements of agricultural tractors during field operations has been one of the point of great concern in the United States and West Europe. Throughout the past three decades, they were able to achieve an outstanding progress of saving fossil fuel and innovating alternative sources of energy and developing non-conventional fuels other than fossil fuel. One of the resolutions for saving energy is to optimize the use of fuel in agricultural practices. Clark and Vande Linde (1993) (Coding Taylor's estimation (1980)), stated that in the U.S.A., **for each 1% improvement in tractive efficiency, approximately 75 to 80 million gallons of fuel could be saved annually!.** This rate was most probably based on the number of working farm tractors and their engines power size. However, it is an astonishing rate of fuel saving from rising tractive efficiency by 1%. They originally developed a tractor mounted ballast system, and designed a hardware and software system for rapid static ballasting of tractors. This was to improve drawbar pull, reduce travel reduction, and raise tractive efficiency or, save fuel according to Taylor's results (1980).

On the other hand, Gomaa and Kabeel (1996) developed a set of twenty engine operating points for John Deere 4055 - 110 horsepower tractor, through the Gear up - Throttle down “GUTD” technique, where each point was evaluated between its input and output power. If the tractor operator understands the characteristics of the engine performance, it is possible for him to select engine speed and gear ratio combinations which will minimize the engine specific fuel consumption. However, this can be done through a continuous variable speed transmission system. If this is combined with an effort to improve tractive efficiency by varying loading level and/or tyre pressure, considerable gains in overall efficiency can be obtained, and translated to fuel savings. Al-Hamed et al. (2001) used Wismer and Luth pull and tractive efficiency estimation functions (1974) to determine traction coefficients under three fixed levels of tyre pressure. The equations coefficients have constant values associated with each tested tyre pressure. These coefficients were variably determined according to the specified working conditions using the formulae developed by Gomaa (2006). Finally the original coefficients of Al-Hamed et al. (2001) were replaced by the estimated ones to determine the related tractive efficiency to the applied conditions. Gomaa and Sabbah (2004) simulated the behavior of tyre motion resistance, work done in soil compression and soil-tyre parameters. They derived functional relationships to simulate the effect of tyre pressure reduction on dynamic load as measured by Burt and Bailey (1982).

The present study aims to benefit from Taylor's investigation (1980) in achieving fuel saving, by selecting the best engine operating point for best combination of loading and tyre pressure levels. Tractive efficiency and specific fuel consumption corroborate each other, and may have the same indication; but in different perception. Hence, fuel consumption rate is considered in this study as another indicator along with tractive efficiency for direct indication of fuel saving.

METHODOLOGY

1- Engine operating range

The twenty engine operating points for John Deere 4055 - 110 horsepower tractor, developed by Gomaa and Kabeel (1996), were utilized in this study to establish a feasible tractor engine operating range (surface). They selected five levels of constant forward speed for plowing by chisel plow.

Each level was applied by four different combinations of gear number and throttle position, to maintain the same speed level constant as indicated in Table (1).

2- Loading levels

Gomaa and Kabeel (1996) conducted their traction experimentation under two different loading levels, by chiseling at 10, and 15 cm depth, of 910.426, and 980.564 kPa penetration resistances respectively. These loading levels were taken in this study where, the exerted horizontal pull measured at the twenty engine operating points associated with 10 and 15 cm depth is used in traction performance estimation of each point.

3- Tyre pressure levels

Gomaa and Sabbah (2004) used the experimental data from Burt and Bailey (1982), to simulate the percent of decrease in dynamic load associated with the applied decrease in tyre pressure by Al-Hamed et al. (2001). They deduced mathematical relationships which were used in the present study to simulate the variation in traction performance when tyre pressure decreased from 120 to 80 kPa.

4- Algorithm of computer simulation program

The program algorithm is based on the specifications and dimensions of John Deere 4055 - 110 horsepower tractor (80.96 kW), utilized by Gomaa and Kabeel (1996) where their measured **DRAFT** was subjected to the above mentioned loading levels conditions, and operating tyre pressure of 125 kPa; which is approximately considered 120 kPa by Gomaa and Sabbah (2004) for simulation purpose (to be in accordance with tyre pressure condition of the utilized data).

Rear dynamic wheel load **RDWL** is determined in (kN) from tractor balance according to Zoz (1972). Dynamic load on single rear wheel **DL** is calculated as 50% of RDWL:

$$DL = RDWL / 2$$

Since traction performance is simulated under 120, and 80 kPa tyre pressure, the decrease in dynamic load **DL** due tyre pressure decrease under constant net traction was determined as follows:

$$DL_{80} = DL_{120} * (1 - PER)$$

Where, **PER**: is the percent of decrease in dynamic load, as simulated by Gomaa and Sabbah (2004).

Net traction of single rear wheel **NT** is considered as 50% of the measured draft at each operating point:

$$NT = DRAFT / 2$$

Then dynamic traction ratio **DTR** and tractive efficiency **TE** are determined from Al-Hamed et al. (2001) as follows:

$$DTR = A\left(1 - e^{BS}\right) + C \ldots (1)$$

$$TE = \left(1 - S\right)\left(1 - \frac{D}{1 - e^{ES}}\right) \ldots (2)$$

Table (1): Tractor operating table obtained from five speed levels, each with its four "GUTD" combinations for John Deere 4055 - 110 horsepower tractor. (Gomaa and Kabeel (1996)).

Operating Points number	Speed Level	GUTD Comb	Selected Gear No.	Engine r.p.m.	Total Reduction Ratio (N_{engine} / N_{wheels})	Theoretical Speed km/h	Aver. Travel Speed km/h
1	1	1	2	1940	214.84	2.866	**2.818**
2	1	2	3	1600	182.27	2.786	
3	1	3	4	1250	141.57	2.803	
4	1	4	5	1070	122.84	2.817	
5	2	1	3	2140	182.27	3.800	**3.826**
6	2	2	4	1700	141.57	3.812	
7	2	3	5	1485	122.84	3.837	
8	2	4	6	1315	108.27	3.855	
9	3	1	4	2180	141.57	4.798	**4.820**
10	3	2	5	1865	122.84	4.819	
11	3	3	6	1655	108.27	4.852	
12	3	4	7	1425	93.98	4.813	
13	4	1	5	2210	122.84	5.711	**5.730**
14	4	2	6	1950	108.27	5.717	
15	4	3	7	1700	93.98	5.742	
16	4	4	8	1520	83.87	5.753	
17	5	1	6	2280	108.27	6.685	**6.700**
18	5	2	7	1980	93.98	6.688	
19	5	3	8	1770	83.87	6.699	
20	5	4	9	1540	72.82	6.713	

Where, **S** slip, **e** base of natural logarithm, coefficients **A, B, C, D,** and **E** are as estimated by Gomaa (2006):

$$A = K_a\,0.75 \quad ,$$
$$B = -K_b\left(0.3Cn_n\right) \quad ,$$
$$C = -K_c\left(\frac{1.2}{Cn_n} + 0.04\right),$$
$$D = K_d\left(\frac{1.6}{Cn_n} + 0.053333\right) \quad ,$$
$$E = -K_e\left(0.3Cn_n\right).$$

Where, **K_a**, **K_b**, **K_c**, **K_d**, and **K_e** Factors of equivalence for coefficients **A, B, C, D,** and **E** resp., under 120 or 80 kPa tyre pressure (Gomaa (2006)).

Cn: Dimensionless wheel numeric, ($Cn = CI.w.d/DL$ (decimals)).

Cn_n: Wheel numeric for working conditions of new value/s.

CI : Cone index or soil penetration resistance (kPa).

w : Unloaded tyre section width - (m).

d : Unloaded overall tyre diameter - (m).

These coefficients were determined as an average common value of the 4 alternative operating points of each forward speed level (5 levels). They are predetermined from the average dynamic load calculated from the average of the measured draft range of the 4 points of each speed level.

These coefficients identify the reduced or increased slip due to tyre pressure decrease or increase respectively. Slip **S** is determined by rewriting equ.(1) as a function of dynamic traction ratio **DTR** as follows:

$$S = \frac{ln\left(1 - \left(\left(DTR - C\right)/A\right)\right)}{B}$$

Where, $DTR = NT / DL$

Actual speed **V_a** is determined from average theoretical **V_t** given in Table (1):

$$V_a = V_t * (1 - S)$$

Drawbar power **DBP** is determined:

$$DBP(kW) = DRAFT(kN) * V_a(km/h)/3.6$$

Fuel consumption rate **FC** is calculated from thermal efficiency □$_{\mathbf{thrm}}$, considering a transmission efficiency. □$_{trans}$ of 85 %; an average thermal efficiency □$_{thrm}$ of 30 % for diesel engines, a heat value of 11000 kcal./ kg$_{fuel}$, a conversion factor of 427 kg.m / kcal., and diesel fuel density of 0.82 kg / l. Knowing that thermal efficiency is :

$$\eta_{thrm} = (BP/FP) * 100$$

Where, **BP** and **FP** are brake and fuel power resp. Fuel power **FP** is calculated from fuel consumption rate **FC**, the last equation leads to the following form of brake power:

$$BP(kW) = FC(l/h) * 3.2$$

Where, 3.2 is a constant resulted from units conversion. Then **FC** is determined:

$$FC = DBP \ / \ (TE * 3.2 * 0.85)$$

and finally, specific fuel consumption **SFC** is determined:

$$SFC = FC \ / \ DBP$$

RESULTS AND DISCUSSION

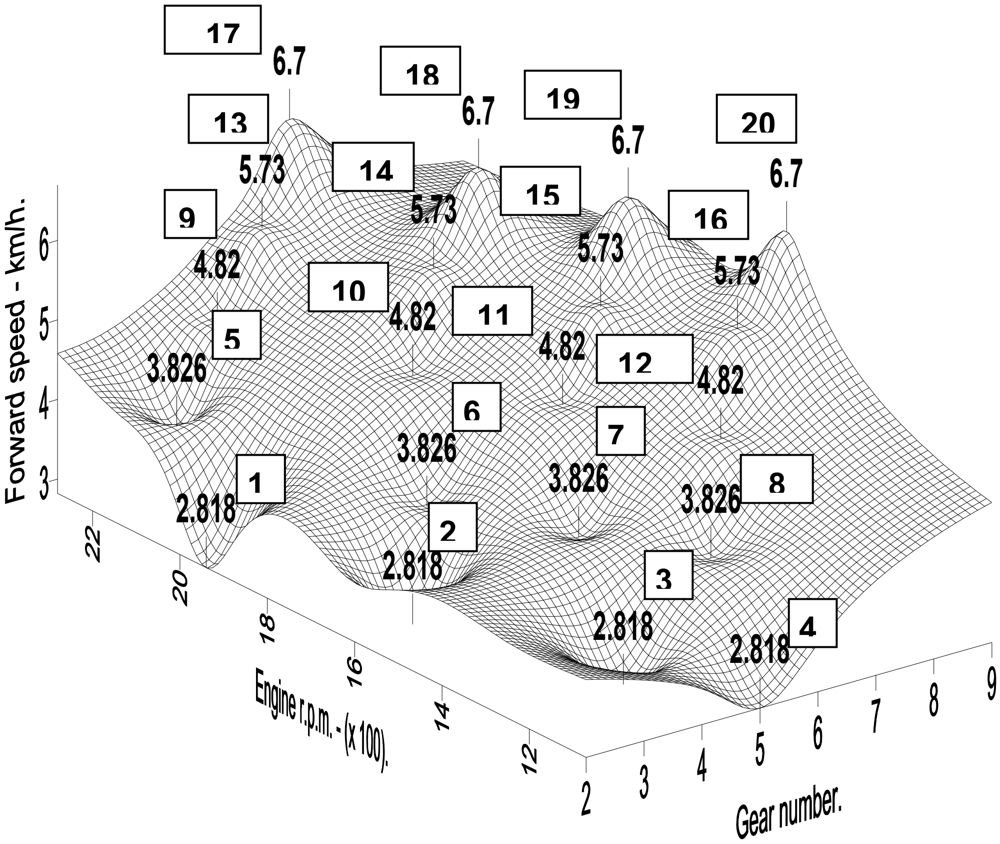

Fig. (1): Forward speed operating surface and the operating point numbers of each speed.

Fig. (1) Illustrates gear shift number, engine r.p.m., and forward speed, in 3-D graph on x, y, and z-axis respectively. This is to show the tractor speed operating surface resulted from applying the Gear up-Throttle down "GUTD" technique. Twenty operating points generated from 4 "GUTD" practices in 5 levels of forward speed (2.818, 3.826, 4.82, 5.73, and 6.7 km/h). Within one speed level, any move from one point of a specific gear number and engine r.p.m., to another one of higher gear number (Gear up) and lower r.p.m. (Throttle down), will produce the same speed but associated with less power. The operating surface would have a different shape if the number of operating points changes. (Operating points depend on number of forward speed levels, and number of “GUTD” combinations specified for each speed).

A) Simulated traction under 1st loading level (Chiseling at 10 cm depth).

The designated point numbers of the different graphing described in the following discussion, is corresponding to the above operating point numbers indicated in Table (1) to produce the five specified forward speeds, as illustrated in Fig.(1).

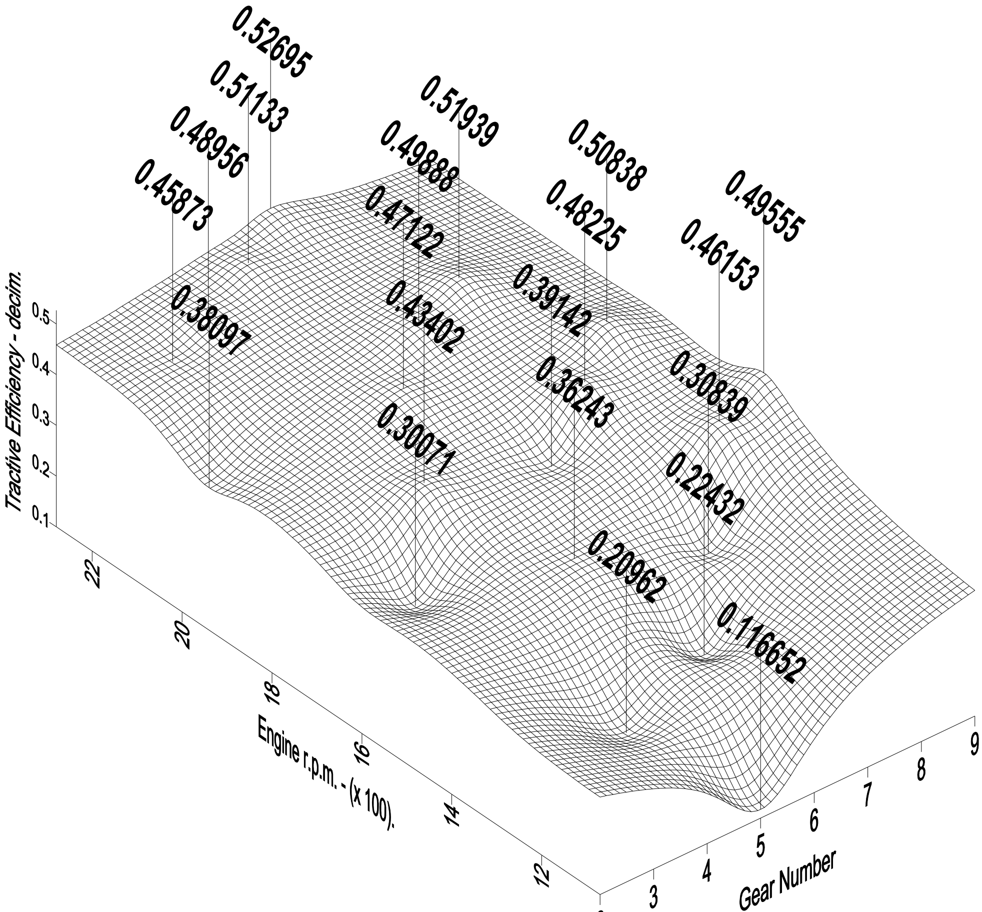

Fig.(2): Tractive Efficiency surface for chiseling at 10 cm depth and 120 kPa tyre pressure.

1. Best selection between engine operating points on the same surface:

Figs.(2&3) show the tractive efficiency and fuel consumption surfaces for chiseling at 10 cm depth and 120 kPa tyre pressure. The selection is generally made on the basis that all efficiency points' values**<**50% are disregarded. Reasonable values of efficiency are: 0.52695, 0.51939, and 0.50838 were associated with the operating points **17**, **18**, & **19** resp. of the highest speed 6.7 km/h, in addition to the value 0.51133 associated with point number 13 of the lower speed 5.73 km/h. Although point **17** is of max. efficiency **0.52695** (min. specific fuel consumption 0.69769 l/kW.h), but also is of max. fuel consumption **12.94822 l/h**, since it is the point of highest throttle and lowest gear within the alternatives of the highest speed 6.7 km/h. Point **13** may be of less efficiency **0.51133** (more specific fuel consumption 0.71901 l/kW.h), but of min. fuel consumption rate **10.13955 l/h**, among the points of tractive efficiency**≥**50%.

To select the best starting point, the decision could be for either one of point **17** or **13**. If point **17** is chosen while tractor was working at point **13**, the shift from **13** to **17** will produce an efficiency gain, expressed by a higher traction performance, in addition to a higher productivity (field capacity fed/h) due to increasing speed, but against a loss or sacrificed fuel consumption:

Efficiency gain = 0.52695 - 0.51133 = 0.01562 or **1.562** % ……… (1)
Sacrificed fuel cons. = 12.94822 - 10.13955 = 2.80867 l/h ……… (2)

If the shift was reversed, from point **17** to **13** a similar amount of the above fuel sacrifice **2.80867 l/h** will be saved, against an efficiency loss or sacrifice of **1.562** % (equal to the above efficiency gain), expressed by less traction performance (more slip and motion resistance), and less productivity due to decreasing working speed.

Efficiency loss = 0.52695 - 0.51133 = 0.01562 or **1.562** % ……… (1')
Fuel consumption save = 12.94822 - 10.13955 = 2.80867 l/h ……… (2')

2. Efficiency gain from reducing tyre pressure (Difference bet^{n} 2 surfaces):

The same traction performance is simulated under a decreased tyre pressure 80 kPa. Fig.(4) shows a higher surface of tractive efficiency due to decreased tyre pressure. The operating points of satisfactory values and maximum efficiency point, are the same of those of tractive efficiency surface at 120 kPa of Fig.(2). So are the operating points on the lower fuel consumption surface shown by Fig.(5). Hence, it is advisable to keep on working on the same point after reducing tyre pressure.

If point **17** is the best applied working point; it is selected as the same best working point after reducing tyre pressure. Efficiency gain from this reduction is determined from the difference between both efficiency surfaces of different tyre pressure (Figs.(2&4)) at their optimum points, (point **17** on both surfaces), as follows:

0.6182 - 0.52695 = 0.09125 or **9.125 %** ……… (3)

If point **13** was selected, efficiency gain will similarly be determined from Figs.(2&4):

0.5884 - 0.51133 = 0.07707 or 7.707 % ……… (4)

3. Fuel save from reducing tyre pressure (Diff. bet^n 2 surfaces):

Similarly, the associated save in fuel consumption with reducing tyre pressure is determined from the difference between the optimum points of both fuel consumption surfaces of different tyre pressure. Fuel save from using point **17** or point **13** on both surfaces of Figs.(3&5)), is determined respectively as follows:

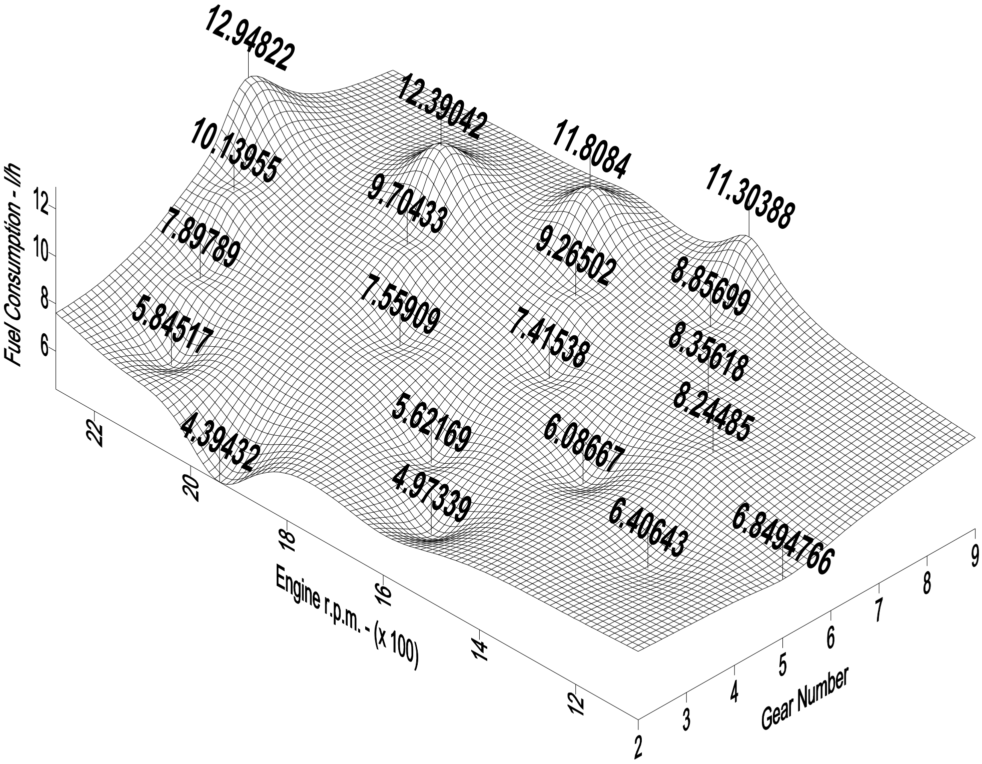

Fig.(3): Fuel consumption surface for chiseling at 10 cm depth and 120 kPa tyre pressure.

12.94822 - 11.40225 = 1.54597 l/h ……… (5)
10.13955 - 9.07296 = 1.06659 l/h ……… (6)

Based on the above selected alternatives, two operating paths **13-17-17** and **17-13-13** could be defined from Table (2):

Table (2): Best paths, working conditions of each operating point and the related figure number illustrating its efficiency and fuel surfaces.

Point number		**Loading level**	**Tyre pressure**	**Fig. number**	
Path 1	**Path 2**			**Efficiency**	**Fuel**
13	**17**	1st	120 kPa	2	3
17	**13**	1st	120 kPa	2	3
17	**13**	1st	80 kPa	4	5

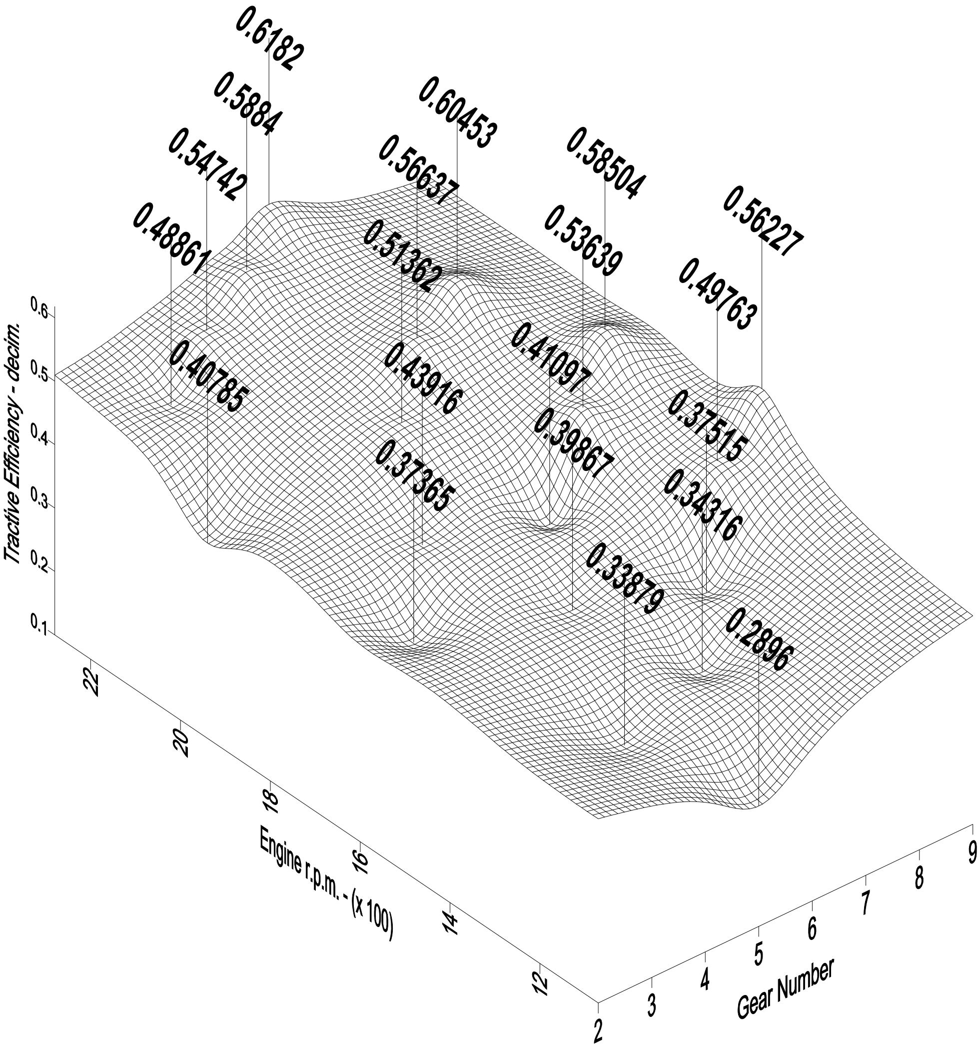

Fig.(4): Tractive Efficiency surface for chiseling at 10 cm depth and 80 kPa tyre pressure.

<u>4. Resultant efficiency gain from varying engine and tyre operating conditions</u>:

<u>Path 13-17-17</u>:

result (1) + result (3)

1.562 + 9.125 = 10.687% ……… (7)

<u>Path 17-13-13</u>:

- result (1’) + result (4)

- 1.562 + 7.707 = 6.145% ……… (8)

5. Resultant fuel save or sacrifice by varying engine & tyre operating conditions:

Path 13-17-17:
- result (2) + result (5)
- 2.80867 + 1.54597 = - 1.2627 l/h (sacrifice) ……… (9)
Path 17-13-13:
result (2') + result (6)
2.80867 + 1.06659 = 3.87526 l/h (**save)** ……… (10)

Farm tractor is supposed to spend about 40 % of its yearly working hours (1000 h), in heavy load field operations; the rest (600 h) is used in light loads operations. Heavy load is represented by primary tillage (breaking-up and inverting soil); in addition to some operations in which PTO shaft must run at the exact 540 or 1000 r.p.m. These functions must be done at full throttle position. Chisel plow is used in cultivation and secondary tillage which are of light load operations (such as planting, weed control for row-crop cultivation, and transportation). They may be done through "GUTD" technique, which is the base of the above applied operating surface.

EVALUATION OF THE ALTERNATIVE PATHS 13-17-17 AND 17-13-13:

So, considering 600 hours per year of tractor light load operations, their evaluation from the side of tractive efficiency and fuel consumption is as follows:

Path 13-17-17:
Rate of sacrificed fuel for each 1% improvement in tractive efficiency:
result (9) / result (7)
- 1.2627 l/h / 10.687% = **- 0.11815 l/h.**
- 0.11815 l/h * 600 h/year = **- 70.89 l/year.**
- 70.89 l/year * 0.80 LE/l = **- 56.713 LE/year or - 4.726 LE/month.**

Knowing that the utilized chisel plow is of 2 - rows, 7 tines - 25 cm spacing, computed slip value at point **17** under 80 kPa tyre pressure is 0.063144, and average theoretical travel speed at the same point is 6.7 km/h. So, assuming a field efficiency of 75 %, the expected actual tractor productivity at the end of the present path is:

(6.7 * (1-0.063144) * 1.75 / 4.2) * 0.75 = **1.96154 fed/h**.
Sacrificed cost per feddan for each 1% of efficiency improvement:
- 0.11815 * 0.80 / 1.96154 = **- 0.0482 LE/fed.**

For the utilized tractor, for each **1%** improvement in tractive efficiency, the yearly rate of sacrificed fuel, related cost, and related cost per feddan are extremely tiny and negligible. If a set of tractors are working in the farm to perform the same task under the same operating conditions (path **13-17-17**), their total sacrificed fuel can be neglected against their resultant of high productivity and traction performance.

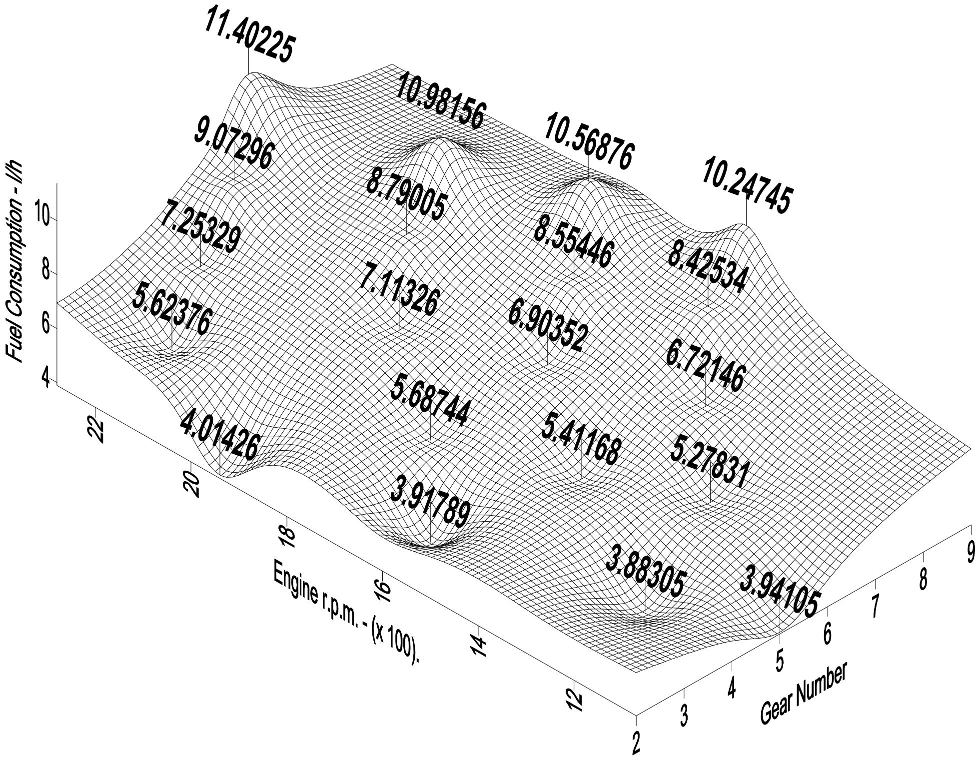

Fig.(5): Fuel consumption surface for chiseling at 10 cm depth and 80 kPa tyre pressure.

<u>Path 17-13-13</u>:

Rate of fuel save for each <u>1%</u> improvement in tractive efficiency:

result (10) / result (8)
3.87526 l/h / 6.145% = **0.63064 l/h**
0.63064 l/h * 600 h/year = **378.384 l/year**
378.384 l/year * 0.80 LE/l = **302.707 LE/year or 25.226 LE/month.**

Computed slip value at point **<u>13</u>** under 80 kPa tyre pressure is 0.050134, and average theoretical travel speed at the same point is 5.73 km/h. the expected actual tractor productivity at the end of the present path is:

(5.73 * (1-0.050134) * 1.75 / 4.2) * 0.75 = **1.7 fed/h**.
Saved cost per feddan for each <u>1%</u> of efficiency improvement:

0.63064 * 0.8 / 1.7 = **0.29677 LE/fed.**
The yearly rate of saved fuel, and related cost, cannot be ignored for the utilized tractor. So, if a set of tractors are working in the farm under the same loading level, and operating conditions (path **17-13-13**), their total saved fuel and cost for each **1%** improvement in tractive efficiency, will be significant against their less productivity and traction performance. However, either one of the above paths can be selected up to the required compromise.

If the nature of the field task is of the light load (traction performance remains under 1st loading level), one must search an engine operating point which compromise between tractive efficiency and fuel consumption; then reduce tyre pressure level as previously demonstrated through calculation steps 1 to 5. If the field task demands operating the tractor under higher loading level, the following discussion will cover the probable cases of traction performance under such condition.

B) Simulated traction under 2nd loading level (Chiseling at 15 cm depth).

Traction performance was simulated under higher loading level, (chiseling depth 15 cm) under both of the same tyre pressure levels. If the tractor is started working directly under the 2nd loading level, the above calculation steps under the 1st loading level could similarly be applied to the 2nd loading level to detect efficiency gain or loss and fuel save or sacrifice.

Fig.(6) illustrates that operating the tractor under the 2nd loading level has generally raised the resulted tractive efficiency surface, and revealed a different operating point of maximum efficiency. Point **17** of maximum tractive efficiency **0.52695** at 6.7 km/h speed under 1st loading level and 120 kPa tyre pressure (Fig.(2)), moved to become point **6** of the maximum value **0.5513** at 3.826 km/h speed on the resulted tractive efficiency surface under 2nd loading level and same tyre pressure 120 kPa (Fig.(6)); while point **4** is of less efficiency 0.53279 on the same surface, but of minimum fuel consumption **5.24195 l/h** at 2.818 km/h speed on the fuel surface under the same loading level and tyre pressure. When tyre pressure is reduced to 80 kPa under 2nd loading level, the point of maximum efficiency moved again to become point **5** of the value **0.65249** on the new efficiency surface, at the same 3.826 km/h speed (Fig.(8)), while point **4** of less efficiency 0.62179 on the same surface, is still of minimum fuel consumption **4.63007 l/h** at 2.818 km/h speed on fuel surface under the same conditions (Fig.(9)).

If the tractor is working under 1st loading level and the required field task demands operating the tractor under higher loading level for better field operation quality, and higher field efficiency; operating conditions are proceeded and shifted from the 1st to the 2nd loading level, under the same tyre pressure 120 kPa first, then under reduced tyre pressure 80 kPa for better efficiency and fuel results.

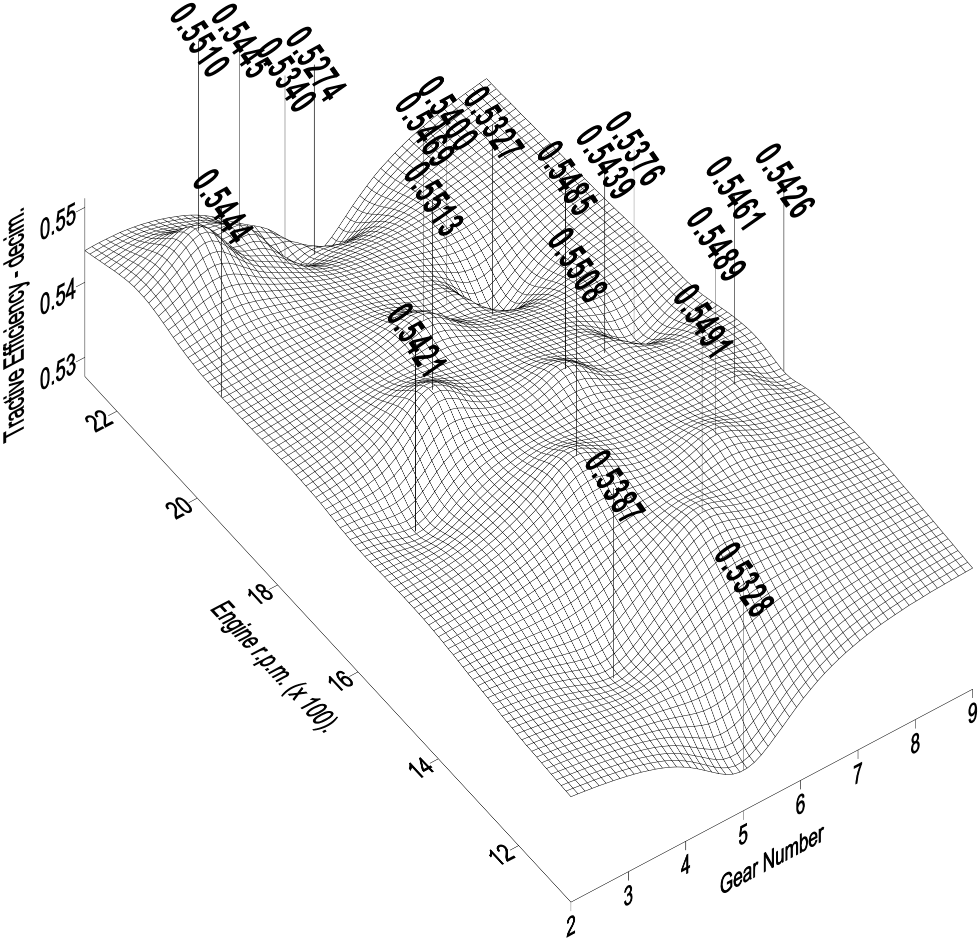

Fig.(6): Tractive Efficiency surface for chiseling at 15 cm depth and 120 kPa tyre pressure.

So, one of two paths could be selected, the path of higher efficiency gain **13-17-6-5** or higher fuel save **17-13-4-4**. Both are passing from 1st to 2nd loading level, where tyre pressure is reduced from 120 to 80 kPa under 2nd loading level as indicated in Table (3)

Table (3): Best paths, working conditions of each operating point and the related figure number illustrating its efficiency and fuel surfaces.

Point number		**Loading level**	**Tyre pressure**	**Fig. number**	
Path 1	**Path 2**			**Efficiency**	**Fuel**
13	**17**	1st	120 kPa	2	3
17	**13**	1st	120 kPa	2	3
6	**4**	2nd	120 kPa	6	7
5	**4**	2nd	80 kPa	8	9

1. Efficiency gain from raising loading level under same tyre pressure 120 kPa (Difference bet^n 2 surfaces):

Efficiency gain from raising loading level is determined from the difference, between optimum points **17** and **6** in the path **13-17-6-5** on both efficiency surfaces associated with 1st and 2nd loading level resp., under the same tyre pressure 120 kPa (Figs.(2&6)):

0.5513 - 0.52695 = 0.02435 or **2.435 %** ……… (11)

Efficiency gain between points **13** and **4** on the same surfaces in the path **17-13-4-4:**

0.53279 - 0.51133 = 0.02146 or 2.146 % ……… (12)

2. Fuel consumption save from raising loading level under same tyre pressure 120 kPa (Difference bet^n 2 surfaces):

The associated save in fuel consumption with the last efficiency gain from raising loading level, is determined from the difference between the optimum points **17** and **6** in the path **13-17-6-5** on both fuel consumption surfaces of different loading levels (Figs. (3&7)), as follows:

12.94822 - 8.21434 = 4.734 l/h ……… (13)

And the difference between points **13** and **4** on the same surfaces in path **17-13-4-4:**

10.13955 - 5.24195 = 4.8976 l/h ……… (14)

The last efficiency gain (result (11)) is less than which obtained from efficiency gain by reducing tyre pressure under the same 1st loading level (result (4)), but the chance is still available to improve result (11) by reducing tyre pressure as long as traction performance is continued under the 2nd loading level.

3. Efficiency gain from reducing tyre pressure (Difference bet^{n} 2 surfaces):

Traction performance under 2nd loading level is simulated at a decreased tyre pressure 80 kPa. Maximum efficiency, moved from point **6** (**0.5513**) on efficiency surface of the 2nd loading level at 120 kPa tyre pressure (Fig.(6)), to become at point **5** (**0.65249**) on the efficiency surface of the 2nd loading level at 80 kPa tyre pressure (Fig.(8)). So the efficiency gain from this tyre pressure reduction through the path **13-17-6-5** is:

0.65249 - 0.5513 = 0.10119 or **10.119 %.** ……… (15)

While through the path **17-13-4-4** between points **13** and **4** on the same surfaces is:

0.62179 - 0.53279 = 0.089 or 8.9 % ……… (16)

4. Fuel consumption save from reducing tyre pressure (Diff. bet^{n} 2 surfaces):

The associated save in fuel consumption with reducing tyre pressure is determined from the difference between the optimum points of both fuel consumption surfaces of different tyre pressure under 2nd loading level (points **6** and **5** in the path **13-17-6-5** on surfaces of 120 and 80 kPa in Figs.(7&9) resp.)

8.21434 - 7.37948 = 0.83486 l/h ……… (17)

The difference between points **13** and **4** on the same surfaces in path **17-13-4-4** is:

5.24195 - 4.63007 = 0.61188 l/h ……… (18)

5. Resultant efficiency gain from varying engine operating point, raising loading level, and reducing tyre pressure:

Path 13-17-6-5

result (1) + result (11) + result (15)

1.562 + 2.435 + 10.119 = 14.116 % ……… (19)

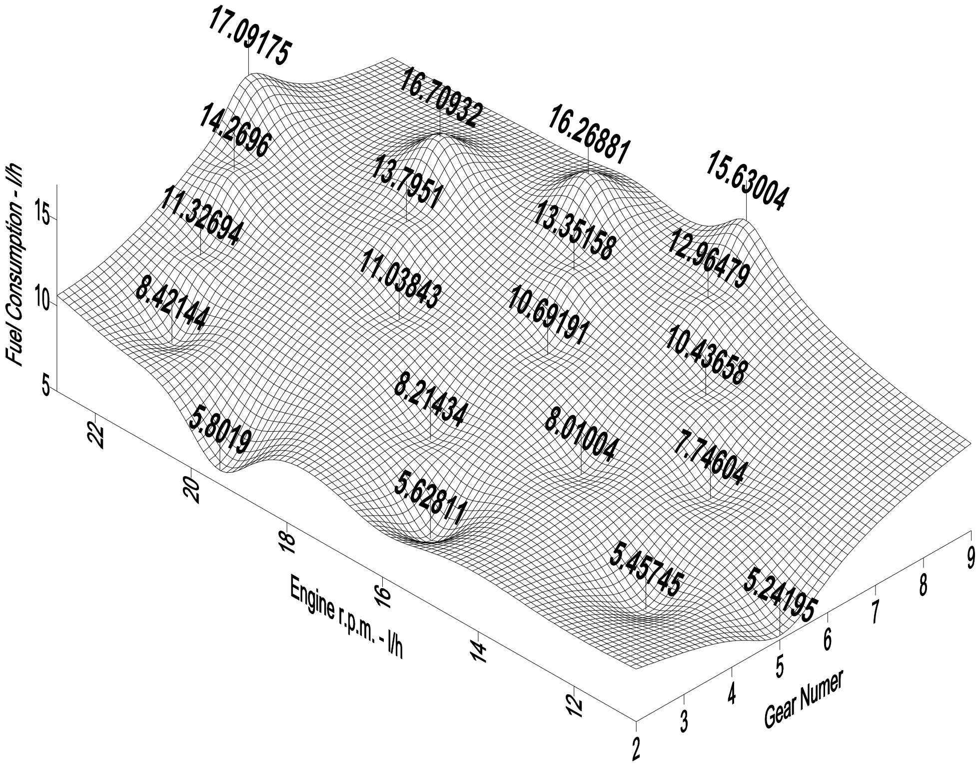

Fig.(7): Fuel consumption surface for chiseling at 15 cm depth and 120 kPa tyre pressure.

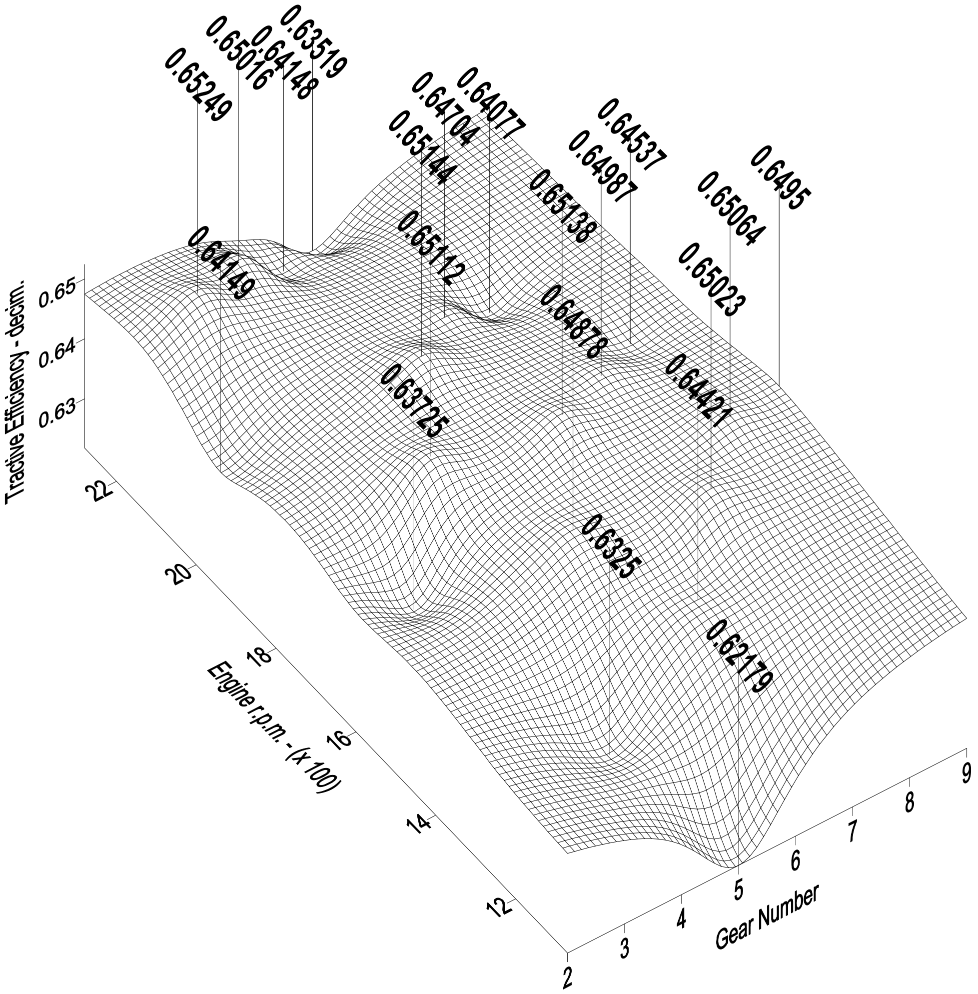

Fig.(8): Tractive Efficiency surface for chiseling at 15 cm depth and 80 kPa tyre pressure.

Path 17-13-4-4

- result (1’) + result (12) + result (16)

- 1.562 + 2.146 + 8.9 = 9.484 % ……… (20)

6. Resultant fuel consumption save from varying engine operating point, raising loading level, and reducing tyre pressure:

Path 13-17-6-5:

- result (2) + result (13) + result (17)

- 2.80867 + 4.734 + 0.83486 = 2.76019 l/h ……… (21)

Path 17-13-4-4

result (2') + result (14) + result (18)

2.80867 + 4.8976 + 0.61188 = 8.31815 l/h ……… (22)

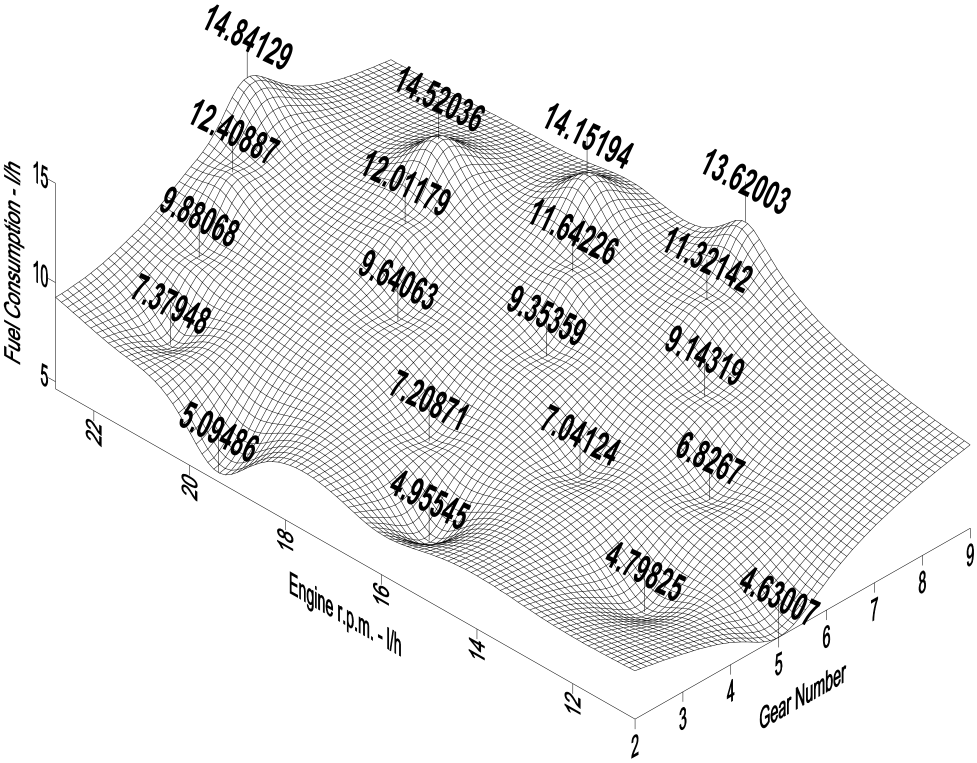

Fig.(9): Fuel consumption surface for chiseling at 15 cm depth and 80 kPa tyre pressure.

EVALUATION OF THE ALTERNATIVE PATHS 13-17-6-5 AND 17-13-4-4:

Path 13-17-6-5

Rate of saved fuel for each 1% improvement in tractive efficiency:

result (21) / result (19)

2.76019 l/h / 14.116 % = **0.195536 l/h**

0.195536 l/h * 600 h/year = **117.3217 l/year.**

117.3217 l/year * 0.80 LE/l = **93.8574 LE/year or 7.82 LE/month.**

Computed slip value at point **5** under 80 kPa tyre pressure is 0.087806, and average theoretical travel speed at the same point is 3.826 km/h. the expected actual tractor productivity at the end of the present path is:

(3.826 * (1-0.087806) * 1.75 / 4.2) * 0.75 = **1.0906 fed/h**

Saved cost per feddan for each 1% of efficiency improvement:
0.195536 * 0.8 / 1.0906 = 0.143434 LE/fed.

Path 17-13-4-4
Rate of saved fuel for each 1% improvement in tractive efficiency:
result (22) / result (20)
8.31815 l/h / 9.484 % = **0.877 l/h**
0.877 l/h * 600 h/year = **526.243 l/year**
526.243 l/year * 0.80 = **420.994 LE/ year**

Computed slip value at point **4** under 80 kPa tyre pressure is 0.056973, and average theoretical travel speed at the same point is 2.818 km/h. The expected actual tractor productivity at the end of the present path is:

(2.818 * (1-0.056973) * 1.75 / 4.2) * 0.75 = **0.83 fed/h**
Saved cost per feddan for each 1% of efficiency improvement:
0.877 * 0.8 / 0.83 = **0.845 LE/fed**

The results showed that both paths, don't imply any efficiency loss or fuel sacrifice. The 1st path is of higher efficiency gain, the 2nd is of higher fuel save. For the utilized tractor, for each **1%** of efficiency improvement in the path **13-17-6-5**, the yearly rate of fuel save **117.3217 l/year**, and the related saved cost **93.8574 LE/year**, are significantly less than those of the path **17-13-4-4**: **526.243 l/year** and **420.994 LE/ year**; while the difference between them in the progressed productivity and traction performance is insignificant. If a set of tractors are working in the farm to perform the same task, it is advisable to orientate their performance through the 2nd path **17-13-4-4**. However, It could be noticed that one can deduce **80** operating paths from the twenty operating points under two loading and two tyre pressure levels. The selection may satisfy either of the following benefits without the others: most efficient performance or maximum amount of fuel saved or maximum productivity; or compromise between them up to user objectives, requirements, and priorities.

CONCLUSION

An operating surface (3D-map) is graphed and used to illustrate the variation in farm tractor performance. Traction performance is simulated under two loading levels and two tyre pressure levels. The surfaces of tractive efficiency and fuel consumption rate are the main indicators to express this variation. The surface is originated from a definite range of operating forward speed (5 levels), each speed was applied though 4 alternatives of different engine operating points, by means of the Gear up - Throttle down technique which resulting in 20 different operating points. Selection of best points produces the best paths to satisfy max efficiency gain or max fuel save, or to compromise between both of them. One case, when the selected path include a shift from an operating point to another better one on the same loading level and tire pressure surface, then to another better point on a reduced tyre pressure surface under the same loading level, up to the field task requirements; such as the path **17-13-13**, which attained **378.384 l/year** of fuel save from simply **1%** improvement in tractive efficiency, corresponding to an amount of **302.707 LE/year** of saved costs by the utilized tractor. Another case, when the selected path include a shift from an operating point to another better one on the same loading level and tire pressure surface, then to another better point on a higher loading level surface, then to another better point on a reduced tyre pressure surface under the last higher loading level, up to the field task requirements; such as the path **17-13-4-4** which attained **526.243 l/year** of fuel save from simply **1%** improvement in tractive efficiency, corresponding to an amount of **420.994 LE/year** of saved costs by the utilized tractor. The more the improvement in tractive efficiency is achieved, the more the fuel or fuel cost is saved from the same tractor, or from the same number of working tractors in the farm.

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الملخص العربى

ألتنبوء بأفضل أداء للجر تحت تأثير ظروف تشغيل مختلفة

أحمد السيد جمعة*

قسم الأراضي والكيمياء الزراعية(الهندسة الزراعية)-كلية الزراعة (سابا باشا)-جامعة الإسكندرية

تم التمثيل البياني لسطح التشغيل ألتنبوئى لاستخدامه في توضيح التغير في أداء الجرار الزراعي. (وهو بمثابة خريطة ذات سطح طبوغرافي متباين، ثلاثية الأبعاد لعشرون نقطة تشغيل للمحرك، ويمكن استخدامه لبيان كفاءة الجر أو لبيان معدل استهلاك الوقود). ولقد تم محاكاة أداء الجر بواسطة برنامج للحاسب الآلي تحت تأثير مستويين للتحميل ومستويين لضغط هواء عجل الجر. المؤشران الأساسيان المستخدمان في بيان هذا التغير هما كفاءة الجر ومعدل استهلاك الوقود من خلال سطحي التغير لكل منهما. التكوين الأساسي لسطح التشغيل يعتمد على مدى محدد لسرعات التشغيل (خمس مستويات) حيث تتحقق كل سرعة من خلال أربعة بدائل لنقاط تشغيل المحرك، ويستعان في هذا الغرض بطريقة رفع الترس و خفض الوقود، مما ينتج عشرون نقطة تشغيل مختلفة تكوّن ما يسمى بسطح التشغيل. اختيار أفضل النقاط ينتج أفضل المسارات لتحقيق أقصى مكسب في كفاءة الجر، أو أقصى وفر للوقود، أو أفضل توازن بين الاثنين. فمثلا هناك حالتين لتوضيح ذلك، الأولي عندما يشتمل المسار على الانتقال من نقطة تشغيل إلى نقطة أخرى أفضل على نفس سطح التشغيل لمستوى التحميل الأول (المنخفض) و المستوى الأول (المرتفع) لضغط هواء العجل، ثم الانتقال إلى نقطة أخرى أفضل على سطح تشغيل المستوى الثاني(المنخفض) لضغط العجل تحت نفس المستوى الأول للتحميل (المنخفض) وفقا لاحتياجات العمل الحقلي المطلوب. هذه الحالة يمثلها على سبيل المثال المسار 17-13-13 الذي حقق وفر مقداره 378.384 لتر/سنة من الوقود بما يوازى 302.707 جنيه/سنة من مجرد تحسين أو ارتفاع في كفاءة الجر بمقدار 1% فقط للجرار المستخدم .

الحالة الثانية عند يشتمل المسار على الانتقال من نقطة تشغيل إلى نقطة أخرى أفضل على نفس سطح التشغيل لمستوى التحميل الأول (المنخفض) و المستوى الأول (المرتفع) لضغط هواء العجل ثم الانتقال إلى نقطة أخرى أفضل على سطح تشغيل المستوى الثاني للتحميل (المرتفع) ثم أخيرا الانتقال إلى نقطة أخرى أفضل على سطح تشغيل المستوى الثاني (المنخفض) لضغط هواء العجل تحت نفس المستوى الأخير (المرتفع) للتحميل وفقا لاحتياجات العمل الحقلي المطلوب. و هذه الحالة يمثلها على سبيل المثال المسار 17-13-4-4 الذي حقق وفر مقداره 526.243 لتر/سنه من الوقود بما يوازى وفر مقداره 420.994 جنيه/سنه من مجرد تحسين أو ارتفاع في كفاءة الجر بمقدار 1% فقط للجرار المستخدم. و كلما ارتفع المكسب أو التحسن في كفاءة الجر كلما ارتفعت كميه الوقود المدّخرة أو ارتفعت القيمة المدّخرة من تكلفة الوقود لنفس الجرار أو لنفس عدد الجرارات التي تعمل بالمزرعة.