ABSTRACT

TRACTION ASSIST FOR A TWO WHEELED
PADDY TRACTOR

By

S. Gamunu Ilangantileke

Traction problems associated with flooded rice soils have been a major limitation to the adaptation of mechanization in rice producing Asian Countries. Sinkage and loss of traction in agricultural vehicles has been a topic of extensive research in the past and will be in the future. The objective of this study was to develop an effective traction aid which would overcome the difficulty of trafficability in saturated soils.

A traction aid, working on the principle of a cable and winch system was developed. The winch system was attached to the front end of the two wheel paddy tractor and was powered by a drive mechanism connected to the PTO shaft of the tractor. A Capstan drum was attached to the winch system. A rope with one of its ends attached to an anchor outside the field, was wrapped around the Capstan. The free end of the rope was passed through a

shieve arrangement, to help maintain a tension on the rope leaving the Capstan drum. When the Capstan was rotated by means of the drive mechanism connected to the PTO, the tractor pulled itself on the rope and moved forwards. The forward speed of the tractor and speed at which the tractor pulled itself on the rope was matched, to prevent slack on the rope if the rope speed was too slow or dragging of the tractor if the rope speed was too high.

Field tests with the winch system revealed positive results. The tractor was able to travel through a saturated rice field at a speed almost equal to that at which the tractor traveled on a concrete floor. Without the winch system the tractor would not move through the same rice field; but had excessive wheel slipage which caused the tractor to sink into the saturated soil. The significant advantage of the winch system is that the traction aid is independant of the soil condition and therefore can be used with any soil type.

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TRACTION ASSIST FOR A TWO WHEELED PADDY TRACTOR

by

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Dedicated to My Late
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

I - INTRODUCTION

1.1 Rice Cultivation in Sri Lanka

Rice is the most important food staple in many South East Asian Countries, of which Sri Lanka is one. To-date a major portion of the country's food requirements are imported, causing a heavy drain on its foreign exchange resources. Therefore there is an urgent need to increase production by utilization of all available resources to a maximum.

Agricultural production in Sri Lanka can be broadly catagorized into dry-zone agriculture and wet-zone agriculture. The dry-zone agriculture is characterized by large areas of cultivable land. The average annual rainfall is 60 inches and the monthly rainfall distribution follows a distinct bi-modal pattern. About 70% of the total precipitation falls during the North-East monsoonal period (October-January) and the balance during the months of April and May. A short dry spell occurs during February and March, but a long and most pronounced dry period is observed from June to September. At this time of the year the temperature is high, winds are high and the relative humidity low. This results in a high rate of surface evaporation and extremely dry conditions. This region of the Island is therefore appropriately termed the dry-zone. Approximately 60% of the paddy lands in the country with average acreages of 5-10 acres or larger are to be found in these areas. The dry-zone cultivation to-date is mainly rain fed with limited supplementary irrigation facilities. The field sizes are fairly large which enable medium sized tractors to operate. The soil and water conditions of these lands permit the use of tillage machinery without excessive sinkage and traction problems.

The wet-zone on the other hand is characterized by a continuous rain fall pattern. And the land sizes are considerably smaller than those found in the dry-zone. The wet-zone could be divided into the wet highland zone, humid upland zone and the South Western coastal regions of the Island. The coastal belt has problems of water logging due to a high water table. The cultivation is essentially rainfed, and in certain portions, the rate of precipitation is extreamly high, averaging well over 100 inches annually (Arumugam, 1969). Most paddy fields in the highland regions are terraced and therefore the average size of such fields are smaller, in comparison with those of the dry-zone.

Small two wheel walking tractors are frequently used on wet-zone fields, since the use of larger, heavy tractors is limited or practically impossible. The power tillers varying from 4-12 hp. are widely used in Asia for wet soils. Smaller two wheel tractors and equipment are becoming popular due to their success in smaller paddies (Reynaldo M. Lantin & Roberto C. Bantista). The size and inaccessibility of the rice fields as well as their very soft soil nature, limits the use of larger four wheel tractors. About 30%

of the total area of rice cultivated in Sri Lanka belongs to the wet-zone cultivation.

1.2 The Problem

The main problem in mechanizing paddy cultivation is the development of a suitable traction device for operation in saturated soils (Ratnatunga, 1969). A very low, soft-soil (especially wet-zone) trafficability in the flooded rice fields, has resulted in excessive bogging (sinkage) of tillage machinery. A considerably amount of labor, time and energy is lost in attempting to cultivate in soft soils, as well as the extra time necessary to remove sunken machinery from these fields.

Timeliness of tillage operations is a most important consideration in the mechanization of rice in these high precipitation areas. Timeliness and quality land preperation can greatly influence the growth of rice. Poor and untimely land preperation is conducive to serious weed problems and plant exposure to harmful chemical substances (Ponnamperuma, 1967). A loss of a day or two in tillage operations may cause postponment of sowing and other cultivation operations for a week or two. The drudgery involved, as well as the inefficient use of tillage machinery in soft boggy fields have led farmers to either under utilize or completely abandon the land.

1.3 The Objectives

The objectives of this project was to find a suitable traction device, that would provide efficient movement of tillage machinery in highly saturated rice soils. This would permit tillage operations to be performed at the optimum time with greater efficiency while at the same time utilizing labor, time and energy inputs to a maximum. By improving the efficiency of tillage operations in these flooded soils, a considerable increase in production as well as utilization of abandoned paddy lands, could bring about a considerable increase in the rice output of the country. Specific objectives of the project were:

1. To design and construct a suitable traction aid, for a two wheeled tractor.
2. To test the principle of the traction aid with regards to its efficiency and trafficability in the flooded rice field, as against the tractor without such a device.
3. To analyze the findings and provide recommendations, for its implementation and introduction.

II - LITERATURE REVIEW

Traction problems associated with flooded rice soils have been a major limitation to the adaptation of Mechanization in rice producing Asian countries. Sinkage of agricultural machinery has been a topic of intensive research in the past as well as in the present. The objective is to develop an effective traction aid which will overcome the difficulty of trafficability in saturated soils.

Allen and Hayes (1953) while investigating the mechanical cultivation of wet paddy in Malaya showed that manoeuvrability of implements is extremely difficult when cultivating heavy land overlaid with perhaps two or three inches of water.

Grist (1965) indicated that in many rice producing countries most of the best land suitable for rice cultivation and future development, may depend almost entirely on the reclamation of swamps, silts, silty soils and peat lands which have little support for wheel or track equipment. Despite the realization that development of "bottomless" land must make use of floatation methods, little progress has been made in devising a suitable means.

"Sight of a tractor bogged down in a flooded field is spectacular. This problem must be overcome if tractors are to be practical and widely used in flooded fields" Stout (1966). He indicated that the ability of a tractor to pull an implement under adverse conditions existing in wet paddies, is a subject of prime importance.

Johnson (1971) showed that the importance of mobility in rice fields, especially in land preperation, harvesting and hauling of harvested grain, is because, these operations require most of the power needed in rice production.

In published reports on the conference of Rice Research and Training in the 1970's (IRRI 1969), it was recognized that in the next decade, the engineers of the Institute should concentrate their research on developing complete designs for simple power operated equipment for rice mechanization. The problem to be faced pertained to designs for both, large and medium sized tractors for high traction in wet fields and mobility under wet low-land conditions.

Gee-Clough and Chancellor (1974) showed that, extremely unfavorable conditions prevailed for vehicle traction and mobility in saturated land preperation. The problems prevalent in different Asian Countries have effected the scale and type of technology development.

> "It is therefore necessary to device new or adopt existing machines to suit the conditions of each type of soil". Grist (1965).

Numerous traction aides have been developed since mechanical rice cultivation was started. Many contributions have been made by the International Rice Research Institute in the Phillipines.

Half-track machines have been developed and operated successfully in some wet soil conditions (1955, Annual Report of the Gambian Rice Farm). Track layers with wide plates or swamp blocks have been successful on bottomless mineral soils, Allen and Hayes (1953). Although mobility is increased, the cost is high. Track laying combines in California, USA have a high initial cost and their maintainance costs are above those for wheel vehicles, particularly in wet, abrasive soils. Track laying machines usually have a very low clearence and are more difficult to extricate when bogged. They are also limited in so far as the mounting and controlling of implements. Therefore track layers cannot be satisfactorily adapted for wet paddy cultivation (Stout 1966).

Mayne (1956) observed that cage extentions beyond the standard pneumatic tires increased stability and floatation. The extentions were about 12 inches wide and slightly less in diameter than the tires, so that road travelling was not affected. Standard tractors with cage wheels exert soil pressures of 3 to 4psi. They worked well on soils with a cone index above 40psi at 12 inch depth; but on soils with a cone index below 30psi at 15 inches, the tractor front end elevated and the rotovator became buried, thus causing bogging (IRRI 1963). Tires with cage wheel extentions have good traction in most rice soils. The cage wheel increased the area of soil subject to shear and served as a puddling tool (Stout 1966). In tests conducted at CRRI in India (1969) cage wheels were used for improving traction.

Pneumatic tires with special modifications to their threads were found to be successful in limited cases by Allen and Haynes (1953). A special type of pneumatic tire has been manufactured for working in wet conditions. It was called the "rice special tire" and had high lugs, which tended to be self cleaning (Stout, 1966).

Where there is a hard pan near the surface, standard wheels with strakes have shown improvement in traction over standard wheels without strakes (Allen and Haynes, 1953). A simple strake wheel with five or six 10 x 10 cm. wooden strakes mounted radially on a metal frame has proved to be of some success in Malaysia. The strakes can be extended and locked in position to provide the desired degree of penetration. There were however, many drawbacks. The strakes were not wide enough for adequate traction and they caused a rocking motion to the tractor (IRRI, 1971). They were difficult to adjust, as the wood swelled in water. Large "foot print" depressions were left behind the tractor.

The extendable lug wheels developed in Japan and Great Britain have not been too popular in the tropics due to their high cost (IRRI, 1971). These wheels were made of steel with lugs that could be extended. The lugs were mounted on the edge of the wheel frame and could be locked into position when necessary. Lug wheels provided better floatation and traction, than the cage wheel. Special metal lugs with rubber tips were mounted, both on the inside and outside of the tire, and extended the full tire diameter for best traction (IRRI, 1965). Tires with cage wheels and extendable lugs were also tested in Burma. Trials were made with lugs which could be extended from a wide steel frame similar to a cage wheel. The lugs were extended only under difficult soils. This feature had considerable merit in clay soils where tires and cage wheels have not proven successful (Stout, 1966). An extendable six-lug traction wheel, with blade settings of -5.08, +2.54, -6.35 and +10.6cm. from the tire perifery, was found to be most desirable (IRRI, 1971).

Non-traction dependent tillage devices such as roto-tillers have shown considerable promise under saturated soil conditions. Performance of tractors in wet soils were improved by the added rotary traction which tended to push the tractor IRRI (1963). Conventional rotary tiller blades were however designed primarily for tillage and do not effectively propell the tractor during tillage. A 300cm rotary tiller using Japanese rotary tillers, spirally mounted along a shaft with a distance of 3.5cm between blades was tested. Tillers for dryland condition had blades mounted on hubs spaced 15 to 25cms apart. The cutting pattern of the Japanese blades resulted in long narrow slices as compared to the wide and short pattern left by the conventional tiller. The difference was significant in wet soils as the force resulting from the slice provided floatation and traction (IRRI, 1965). The following advantages were listed in favor of the wide tiller.

1. Less power was consumed in wheel slippage and rolling resistance.

2. The soil surface was left in a more even condition.

3. The wide rotor provided more push to the tractor to assist in overcoming rolling resistence.

Special rotors, square and triangular, were designed and fitted to a 400cm tiller frame. The square box rotor gave more floatation on soft soils, while the triangular rotor gave more penetration on moderately firm soils. Both sets of rotors required less power than those with standard tiller blades and provided push which enabled the tractor to move at a higher speed (IRRI, 1967).

A special push-type tiller was designed at IRRI, with a large diameter tiller rotor and was compared with the conventional type. The push-type, wet-land rotory tiller gave increased ground support and forward push, with alternating cutting and supporting blades. Under similar ground conditions, the push-type IRRI rotary tiller had considerably less rear wheel slippage than the conventional rotary tiller. It was also found that the rotor pushing force was influenced by the peripheral blade velocity and the tiller blade velocity. A slower tiller blade peripheral velocity or higher tractor travel speed decreased the rear wheel slippage, under both soft and hard soil conditions (IRRI, 1968).

A new rotory tiller with eight adjustable blade angles was tried out to find the influence of the blade angle in forward motion. In the tests conducted with angles of 12.5°, 32.5°, 52.5° and 72.5°, the 12.5° blade developed the maximum push. The highest power consumption was at a 32.5° blade angle, although it provided less pushing force than the 12.5° blade (IRRI, 1969).

There is an increased use of small power tillers in Asian Countries ranging from 4-12hp, to provide better trafficability on rice soils than the large 4 wheel tractors. These tillers have special wheels similar to cage wheels for use in flooded soils. With a cone index of 30psi at 9 inches, these tillers moved efficiently but at cone indexes below 20psi at 9 inches, they bogged down. Small tillers with large wheels have ground pressure of 0.5 to 0.7psi and therefore work better than those with smaller wheels on soft saturated soils (IRRI 1963). However, Reynaldo and Bantista have indicated that power tillers with streering clutches and variable speed gear boxes are generally easy to handle but are not very adaptable to soft and deep mud. Westgate (1960) reported that Chinese engineers were developing special tractors for use on paddy fields. Of these, two were selected for production; one a 3.5hp machine and the other a 27hp type. Both had bladed wheels and were light in weight and had good traction, adequate power and manoeuvrability. Hawkings (1958) stated that on dry land most small garden tractors suffer from the lack of wheel grip for heavy operations, and modifications to aid traction in wet fields have been unable to overcome this. He added that it may be possible that two-wheeled rotary cultivators may prove satisfactory if the engine power is mainly used for driving the rotor and not for wheel traction. Special auger wheels for a 5hp tractive type tiller have also been developed (IRRI, 1964).

Tandem tractors have been made by connecting two tractors with front wheels removed. Tandem tractors have four wheel drive, power steering, a center pivot action and weight balance to prevent elevation of the front end. The tandem tractor performed well under certain wet conditions where a single tractor would not (IRRI, 1963). A four-wheel drive tandem unit made by joining two 8.5hp standard tractors helped eliminate bogging and kept the operator from walking in the mud. It was found however, that the unit was under powered and weighed too much in the rear (IRRI, 1964).

A light weight four-wheel riding tractor with independently driven front and rear cage wheels was tested. Land preperation was achieved by inducing a speed differential between the front and rear wheels. For maximum mobility however, the front and rear wheels were driven at the same speed (IRRI, 1969). Two light weight 6hp tractors were hitched together at IRRI in 1970. Several wheels were designed for them, to determine which would best combine traction and tillage. A drum-wheel with tilling blades was most satisfactory in soft soils. Tilling was accomplished when the front wheels operated at 55 to 60rpm and rear at 30 to 35rpm. The machine however bogged down in soft clay soils when the sinkage was equal to the wheel diameter. A major drawback in the differential slip cage-wheel tractor was the difficulty in maintaining a constant speed differential between the front and rear cage wheels which were independently powered. In 1971 at the IRRI, this was overcome by equiping a standard 7hp tiller with an extra pair of cage-wheels which were driven from the tractor wheels through two independent chain transmissions. This tiller had excellent mobility and tillage action in soft paddy fields. They concluded that the concept of a differential slip tiller can provide improved mobility and achieve tillage without additional tillage implements in soft soils IRRI,(1971).

The use of cable operated equipment where cable traction is provided from the bunds for paddy cultivation was introduced in Bologna Italy (Grist, 1965). Powered winches were positioned on the field boundaries with cables as sources of motive power for traversing the implements across the field. A steam-winch operated cable tackle, originally manufactured in England by Fowlers, was thought to be an ideal mechanism for soft-soil land preperation. In this arrangement no parts of the machine were exposed to the mud and therefore no slip occured under any conditions regardless of how adverse (Ratnatunga, 1966). Cable traction devices were tried in Brunei (Grist, 1965), to cultivate their extensive areas of muck soils. Although cable traction in the past was used only for plowing, in Brunei, it was applied to all field implements. The soil was too soft for wheels and tracks, so the implements were carried on sledges. Two tractors on either side of the field were used for the power driven wire rope winches. They concluded that cable operated equipment carried on sledges enabled "bottomless" soils to be cultivated mechanically for rice production.

In an unpublished project proposal made by Chen, he suggested that a stationary engine fixed at a corner of the field could be used to drive a cable with an implement in a field. The speed of the engine was reduced by a gear box for driving two rotating spools. The cable was wraped onto the two spools and the tillage implements were attached to the cable causing it to move up and down the field by reversing the direction of the spool movement. The advantages of such a system were sumarized as: 1) there was no powered machinery in the field and more nearly all engine power can be converted into traction force; 2) different implements can be attached for field operations; 3) it was inexpensive to maintain and own; 4) easy to be manufactured with minimum industrial background and; 5) more comfortable and less noisy during operation.

Crossley and Kilgour, (1973) at the National Institute of Agriculture Engineers in England developed what was termed the "Snail", a low cost primary cultivation implement. This was designed to provide additional power for a walking tractor to plow very hard soils in Malawi, Africa. The implement is attached to a cable which is pulled by a winch operated by the power take off of the tractor. Two men operate this mechanism, one man controls the plow or implement and the other operates the winch and tractor. The tractor moves ahead of the implement to the full cable length and is anchored into the soil. The cable with the implement hooked at one end is then pulled by the winch. When the implement reaches the tractor the winch mechanism is disengaged and the tractor is moved to the full extention of the cable once again. This mechanism was supposed to provide a very efficient pull so as to move the implement through very hard soil, without which the implement would not move.

III - METHODOLOGY

3.1 The Selected Approach

An anchored cable and winch principle was chosen to be used as a traction aid for the tractor. The winch in this approach was to be attached to the tractor and the tractor to pull itself through the mud on the cable anchored outside the field. The advantage of this method is that the tractor can pull itself by its own engine power as well as enable various implements to be attached to it.

The cable on which the tractor pulls itself is attached outside the field and moved at intervals till the end of the field is reached. Details and suggestions for such a movement will be discussed in a later chapter (Figure 4.11).

3.2 Construction of the Winch

A 5hp Kuboto walking tractor similar to those used in Sri Lanka was purchased from Leckler's Garden Center in La Salle, Michigan on a grant given by the FAO, Rome. Work on the construction of the winch began in the Summer term of 1974.

The basic principle of the mechanism was to transfer the driving force for the winch from the PTO shaft of the tractor, and reduce the speed of the PTO shaft to operate the winch so that the cable is moved on the winch, at a speed equal to the ground wheel speed of the tractor. This is necessary for proper working of the winch as well as to have a required tension on the cable. A half-inch Manila rope with breaking strength 1200 lbs was used instead of a steel cable. The rope provided more friction between the surface of the winch and the rope and was also considerably cheaper than the cable. Hereafter it will be refered to as the rope.

The speed of the rope moving into the winch has to be equal to the wheel travel speed of the tractor at all times. If the rope take-up is too fast the tractor would be dragged through the mud without allowing for any wheel assistance. If the rope runs too slowly, too much rope slack causes unwanted wrapping of the rope on the winch surface and a loss of pull results. To achieve proper wrapping of the rope, the following observations and calculations had to be made.

The tractor was driven at three different engine speeds (950, 1200 and 1500rpm) on a concrete floor. The time taken to travel a distance of 24 feet was taken for each engine speed as well as for both 1^{st} and 2^{nd}, low and high gears. The 3^{rd} low and high gears were not used as the speed was too excessive for comfortable operation of the tractor. The third gear is used essentially for transport and haulage of trailers on paved or dirt roads. The PTO rpm was noted for every engine speed, as well as gears used. Time of travel for certain distances provided travel speeds for different gears, as shown in Table 1.

Table 1. --Travel Speeds in Relation to Engine and PTO rmp for Different Gears.

Engine rpm	Gear	PTO rpm	Time to Travel 24ft. in sec.	Travel Speed ft/min.
950	1 low	45	63	22
	2 low	160	15	96
	1 high	71	40	36
	2 high	259	10	144
1200	1 low	55	50	28
	2 low	205	12	120
	1 high	85	30	48
	2 high	330	8	180
1500	1 low	70	40	30
	2 low	--	--	--
	1 high	110	25	57
	2 high	--	--	--

The travel speeds obtained from the above table, were used as the rope speeds for the different gears used. Taking these rope speeds, the revolutions per minute of the winch were calculated from formula (1), normally used to calculate the velocity of belt speeds on a pulley.

$$V = \frac{D\pi}{12} N \qquad (1)$$

where

V = Velocity of the belt, ft/min.

D = Diameter of the pulley, in inches

N = rpm of pulley

The diameter of the winch was taken as 4.75 inches. The winch used for this construction, was a Capstan winch

Table 2.--Winch Speed and PTO/Winch Ratio in Relation to Rope Speed and Engine rpm.

Engine rpm	Gear	Rope Travel Speed ft/min	Winch rpm	PTO rpm	PTO/winch rpm ratio
950	1 low	22	18	43	2.24
	2 low	96	77	170	2.33
	1 high	36	28	70	2.42
1200	1 low	28	22	55	2.40
	2 low	120	96	205	2.12
	1 high	48	38	85	2.20
	2 high	180	140	330	2.28
1500	1 low	36	28	71	2.41
	2 low	--	--	--	--
	1 high	57	46	100	2.59
				Mean Ratio	2.31

manufactured by Parker Thompson Associates, Fenton, Missouri. The diameter of the winch in the manufacturers specifications was 4.25 inches but when considered with the rope, the diameter for calculations was taken as 4.75 inches. 0.25 inches were added on either side of the winch drum for the half inch Manilla rope.

By using formula (1) the winch rpm was calculated for different travel speeds obtained from Table 1. After the winch rpms were obtained for the different gears and travel speeds of the rope, the ratio between the PTO rpm and winch rpm was calculated and tabulated as seen in Table 2.

The information in Table 2, reveals that on an average, the reduction between the PTO shaft and the winch should be 2.31:1. It was not possible to reduce this to the exact value unless gear wheels were designed for such a reduction. The sprocket wheels for reduction were obtained from available parts in the Agricultural Engineering Department and the closest sprocket wheel necessary for the reduction was chosen.

Formula (2) was used to calculate the diameter of the driving pulley.

$$\frac{n_1}{n_2} = \frac{d_2}{d_1} \qquad (2)$$

where

d_2 = The diameter of the driven pulley

d_1 = The diameter of the driving pulley

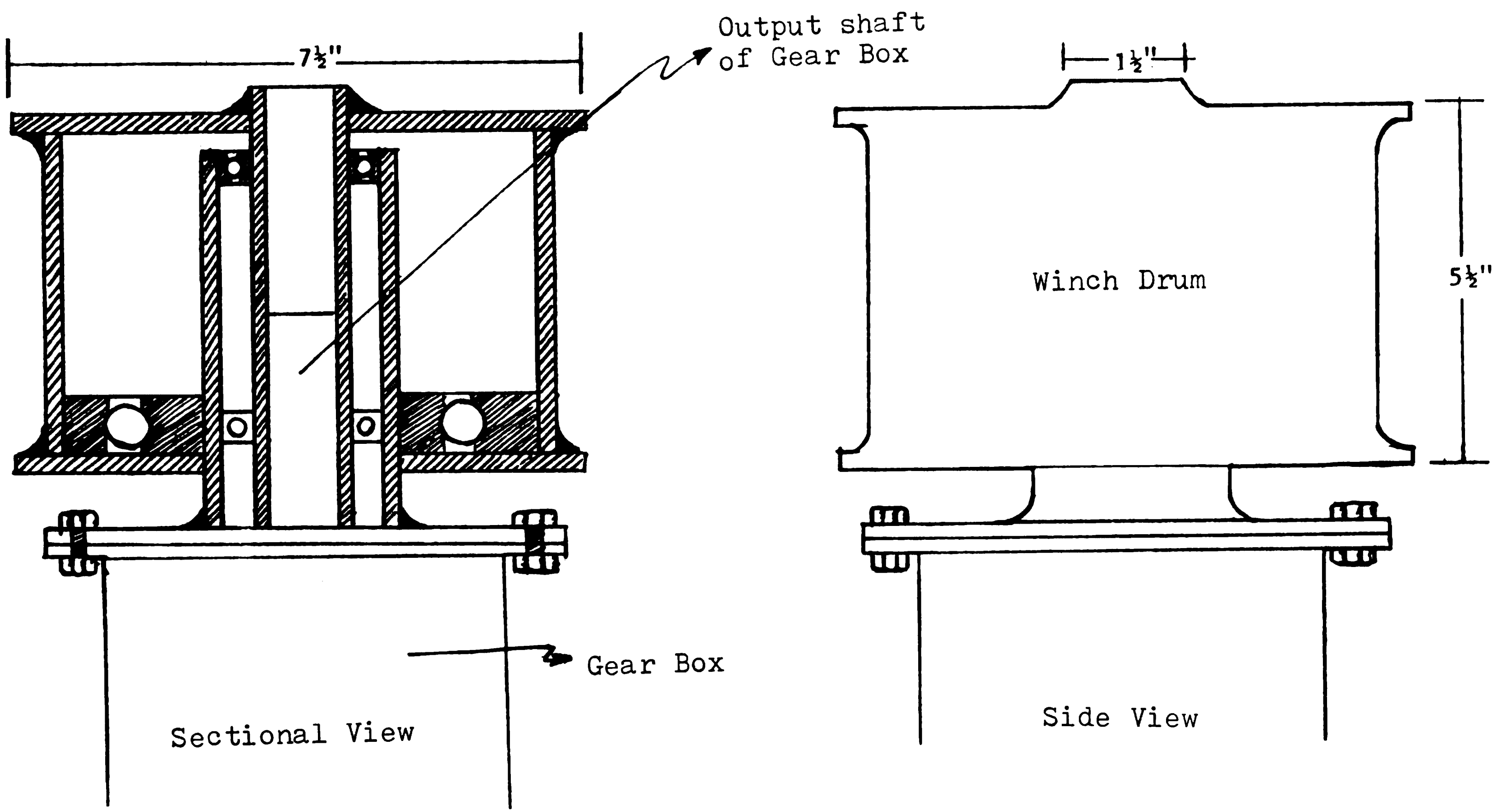
n_1 = Rpm of driving pulley

n_2 = Rpm of driven pulley

The diameter for the driving pulley was calculated keeping the diameter of the driven pulley at a maximum of 8 inches, for ease of construction. From the calculation a driving pulley of 3.46 inches was needed. The closest size available was 3.5 inches.

Prior to using the winch supplied by Parker Thompson Associates, a winch drum was constructed in the shop. Figure (3.1) shows the sketch of the winch drum constructed. There were several drawbacks and limitations in this construction. The drum was too heavy for the tractor and caused the tractor to tilt downwards. Therefore

Figure 3.1 A Sketch of the Winch Drum Constructed in the Shop. The Drum Proved to be Unsuccessful.



operation of the tractor from behind was extremely difficult. Addition of weight to the rotovator case, did not help correct this situation. The drum was made of a six inch diameter galvanized pipe and therefore did not provide an adequate friction surface for the rope to pull the tractor forwards. Continuous slip of the rope on the drum surface resulted.

Addition of a rubber lining on the drum caused excessive wrapping of the rope. Excessive wrapping was due to the high friction surface created by the rubber lining. Crowding of the rope resulted. The rubber layer did not provide the necessary slip when excessive loads, were experienced by the drum. When the rubber was used as a friction surface the rope got jammed so badly that it elevated the back of the tractor and made operation from behind impossible. Many tests were performed with this winch without much success. The drum was therefore discarded and a new method sought.

The Capstan drum had been designed and used in a wide variety of pulling and lifting operations in the construction industry. A Capstan drum was tested instead of the winch drum constructed in the shop. The only available Capstan drum in the time period available for testing was at Parker Thompson Associates in Fenton, Missouri and therefore a 500 series Capstan drum was ordered. The increasing contour diameter of the Capstan drum has a progressively longer circumference, which makes the rope wind on the Capstan. The combined axial and circumferential creeping tendency created, increased the frictional quality of the hard anodized Capstan surface and permited a free running take up without rope crowding. The hard coat, heat treated aluminium drum, reduced the weight on the front end of the tractor considerably, compared with the previous drum and thus made operation of the machine easy. On testing, the Capstan drum proved successful and provided efficient pulling of the tractor with the rope.

To effect transmission of the drive from the PTO to the winch a 90° drive gear box was obtained from available parts. The ratio between the horizontal and verticle gear arrangement was 1:1 and therefore the only reduction in gear speed was between the PTO and the input shaft of the gear box.

The reduction in gear speed was brought about using the 3.5 inch sprocket attached to a 1-inch shaft which was subsequently attached to the PTO shaft of the tractor. The 1-inch shaft was machined in the Mechanical Engineering shop with a precision 2 inch long bore of 17mm and an internal $\frac{1}{4}$ inch keyway. The keyway was used to effect the joining of the shaft to the PTO. The keyway prevented damage to the PTO shaft and its bearing at times of a heavy load. A 1-inch pillow block bearing was used to support the shaft.

An 8 inch sprocket was attached to the input shaft of the gear box so that there would be an effective reduction from the PTO to the winch. (A pulley system was used

Figure 3.2 A view of the braces and frames used to support the gear box, extended PTO shaft and all other accessories.

at first, but due to the force generated, the belts slipped. Therefore a positive drive was needed). A 1-inch pillow block bearing was attached to support the shaft. A key was used to fasten the sprocket to the shaft.

Braces and frames to support the gear box and the extended PTO shaft were constructed with 1/8 inch angle iron. Heavy gage metal was used for areas where high force was expected, so that the gear box had enough support for the pull generated by the winch (Figure 3.2).

To attach the winch on to the gear box, a shaft with a one-inch bore to fit into the output shaft of the gear box had to be machined. A threaded end was made to hold the winch in place.

To keep the rope coming off the winch tight, a

Figure 3.3 A closer look at the winch assembly showing the change in direction of the rope by using the pulley arrangement.

mechanism was designed to make use of the drive provided by the input shaft of the gear box. A 5-inch pulley was attached to the shaft. The direction of the rope was reversed by making use of a pulley arrangement shown in Figure 3.3. An idler roller was used to keep the rope tight on to the pulley and this made the shieve pull the rope at the same rate at which it came into the winch. The rope was then laid down on the ground without much tension.

3.3 Construction of the Rice Paddy

The appropriate method to test the mechanism constructed was to run the machine in a saturated field, similar to those in which rice is grown in most lowland rice producing areas. To achieve this objective, it was decided that a rice paddy resembling those found in Sri Lanka would be built in the Soil Science research field at Michigan State University.

Several areas with a high level of water retention were selected. Out of these areas, a plot from a field previously used to grow sweet corn was selected as the most suited, considering the distance from the water source as well as the existing condition of the field. Since most paddies in the wet-zone of Sri Lanka are very small and broken up into small plots (Liyadda's), a suitable field size 100 feet long and 40 feet wide was chosen. This area was plowed and later harrowed to bury the corn stubble left from the previous crop. A dyke was built around the perimeter, so that water could be impounded when ever necessary.

Water was supplied to the field by a series of pipes connected to a water pump supplying the research field. After the dyke was built, water was sent into the field to test the holding capacity of the soil. Water was kept at a 3-inch standing level for about 1-2 hours and then receeded until the water drained out completely, about four hours later. This enabled traction tests to be performed at a water level of 3-inches or more and therefore was very satisfactory. The paddy is illustrated in Figure 3.4. Soil samples were taken at random, to determine the soil texture of the working area.

Figure 3.4 The rice paddy constructed on the Soil Science research field at Michigan State University.

3.4 Field Testing

Field testing was done towards the latter half of October after the winch was constructed and perfected in the shop. Numerous tests were performed on the compound of the Agricultural Engineering Department, to ensure proper working of the winch system before field tests were actually carried out.

The main test criteria was to determine the travel speed of the tractor in the saturated soil, with the winch, as well as without it. To show the differences in travel speeds between different soil conditions, the following tests were performed.

Travel speeds were determined for the two forward gears both on low and high for three different rpms of the engine - (950, 1200 and 1500), on concrete, firm soil, saturated soil and saturated soil with the winch system. Rpms were measured by a tachometer placed at the engine output shaft.

a. Concrete.--The travel time for a measured distance of 20 feet was taken for the different engine speeds and gears, measured on the concrete floor outside the Agricultural Engineering building. Ten travel times were measured for each gear and each engine speed. From these measurements the travel speeds were calculated.

b. Firm Soil.--The tractor was transported to the Soil Science field where the paddy was constructed. Field testing began on the 22nd of October 1974. The soil was relatively dry at the start of the tests. Ten soil samples were taken to determine the moisture content of the soil at the time of testing. Similar tests were performed as those for concrete, for the different engine speeds as well as gear speeds, although in this case, the machine was run without the rotovator, as well as with the rotovator (Figure 3.5). Ten travel times were recorded for each set of engine and gear speeds, for a travel distance of 20 feet. Foward travel speed was calculated from these readings. The engine stalled at all rpms in the 2 high gear, when the rotovator was used and therefore readings were not taken for this gear.

c. Saturated Soil.--The water was let into the field about one hour before the tests were started and the

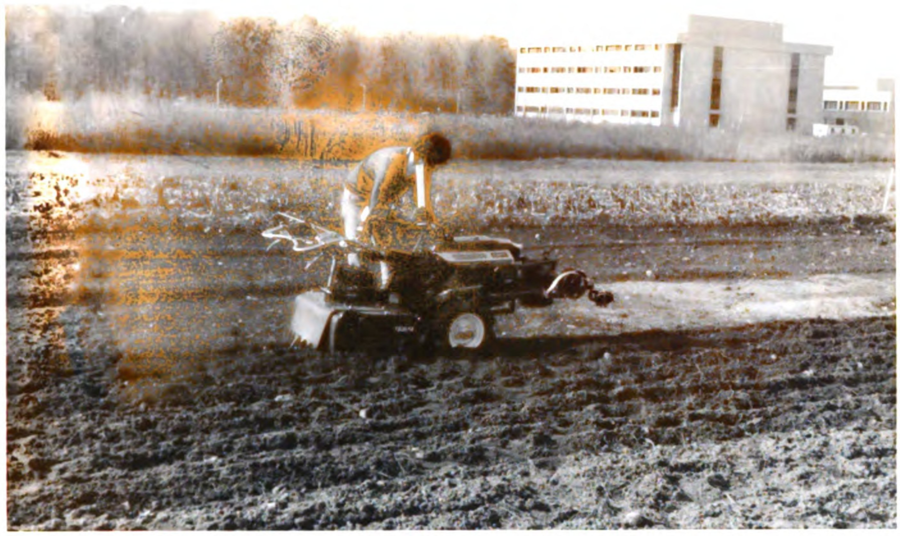


Figure 3.5. Operating the tractor on firm soil conditions with the rotovator.

tractor was put into the field when there was approximately 3-inches of water in the field. This represented a typical wet lowland rice field, where the soil was muddy and provided little support for machinary. The tractor would not move at the engine speed of 950rpm. The engine stalled as soon as the machine entered the field. The tractor did not move at other engine speeds, although at 1500 revolutions it moved about ten feet into the field and then got bogged, (Figure 3.6). Under the saturated conditions, no forward travel speeds were recorded since the tractor did not move.

d. Saturated Soil with the Winch.--The winch system was tested on the field extensively before actual readings were taken. The field was saturated at all times and the rope was located outside of the field (Figure 3.7).

Figure 3.6. The tractor bogged down in the saturated soil without any further movement.

Figure 3.7. The rope is attached to the pickup serving as a anchor located outside the field. The picture illustrates the tractor being pulled through the saturated soil by the winch and rope.

The braces on the pulley that reversed the direction of the rope were weak and kept bending and therefore had to be modified. Continuous testing of the tractor and the functioning of the winch system resulted in the addition of a further set of braces to prevent an upward bending force on the winch braces. After much testing, it was decided that the winch system was ready for field observation.

Ten soil samples were taken to establish the soil moisture content for the tests. Free water in the soil samples was drained out of the containers, leaving very wet soil in the cans. Testing the tractor began by tying one end of the Manilla rope to be used on the winch, to the tow-bar of the pickup used to transport the tractor to the field. The pickup was then reversed, so that the rope was attached approximately at the end of the field.

The free end of the rope was then brought to the opposite end of the field and attached to the winch as follows. The rope was wrapped three times around the winch. The rope was then taken through a guide to the pulley that reversed the direction of the rope (Figure 3.8). The arrow points at the direction at which the rope is anchored. The rope is then guided on to the take-up pulley where it is held in place by increasing the pressure exerted to it by the idler pulley. This is done by tightening the idler pulley on to the rope by using the adjusting nut. This makes the rope turn in the direction of motion of the pulley. The rope coming out of the winch is therefore kept tight and

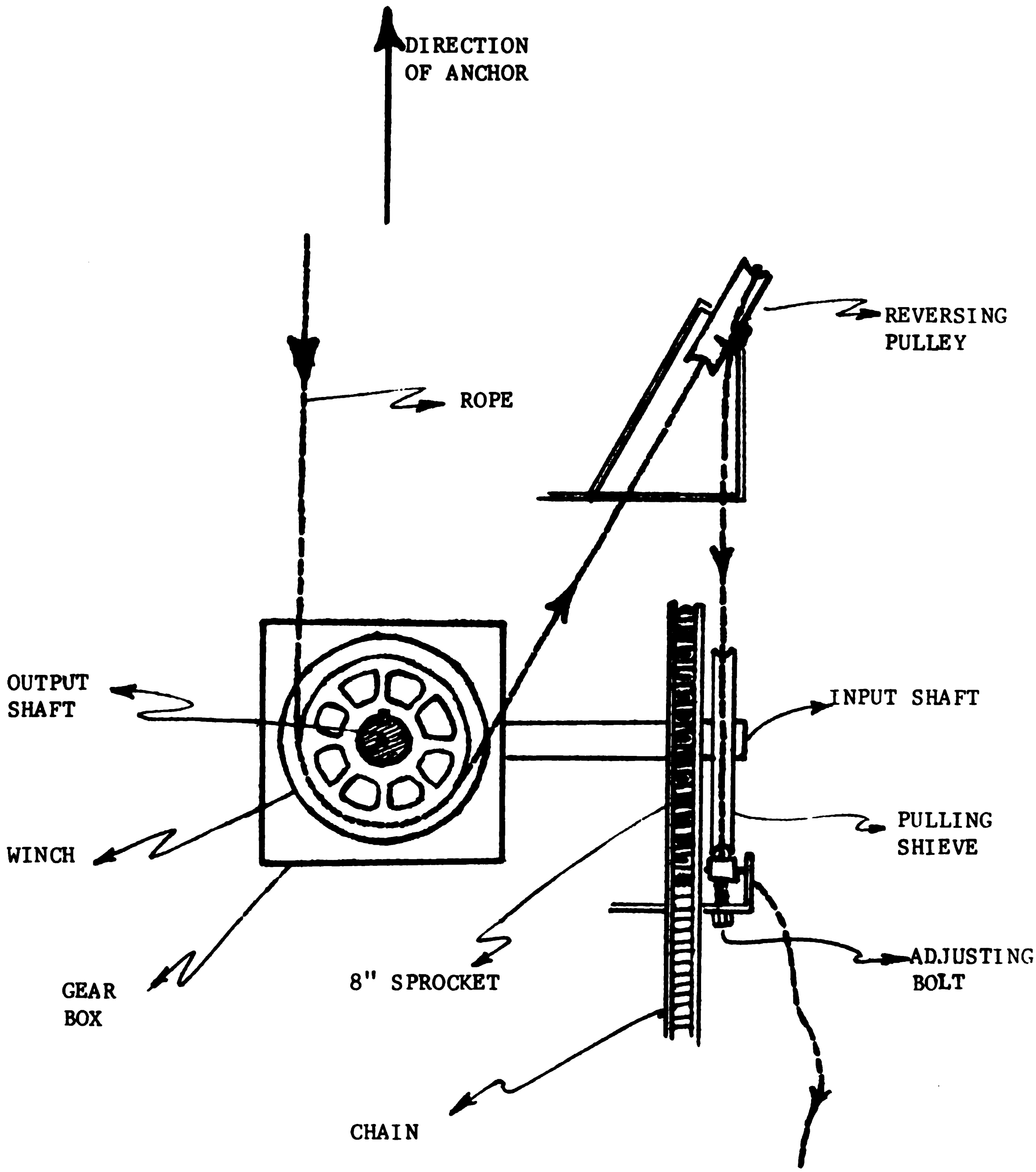


Figure.-- 3.8 A Sketch Showing the Method used to Reverse the Direction of the Rope Leaving the Winch Assembly.

ensures proper wrapping of the winch. A rubber coated pulley in future designs would provide better friction between the rope and the pulley and therefore would not need high pressure from the idler. The system was so constructed that the attachment of the rope to the winch and pulleys, was easy and fast.

Once the rope was attached to the system the engine revolutions were adjusted as before. On the 1st low gear at 950 rpm, the engine stalled as soon as the tractor entered the field. Similar results occured on the high gear too. Therefore at this low engine rpm the tractor would not move even with the help of the winch.

The engine speed was then increased to 1200 rpm where the tractor began pulling itself on the rope by means of the winching system, in both the high and low ratios of the 1st gear. Ten readings of travel time for a distance of 20 feet were taken. The 2nd gear caused the engine to stall and therefore no readings were taken.

Similar readings were taken at an engine speed of 1500 rpm. Ten readings for travel time both for high and low ratios of the first gear, were recorded. The second gear was not used due to the uncontrolable nature of the machine at this high engine rpm.

The pull exerted on the rope by the winch was recorded in lbs of pull. This was done by means of a spring dynamometer attached to the pickup tow bar and the free end of the rope. The dynamometer was previously calibrated in the shop using a 100lb dead weight. Recordings of lbs pull were taken for every 20ft run observed. The rotovator was used in the saturated condition, for all observations made.

Due to bad weather which prevailed during and after the experimenting period further field testing of the machine and system was not possible.

IV - RESULTS AND DISCUSSION

4.1 Presentation of Data

Traction characteristics of Agricultural vehicles are largely governed by the dynamic properties of the soil surface in which they are working. In wet rice soils, mobility of vehicles is restricted by numerous factors, characteristic of the prevailing soil conditions. Tractive effort in soil is developed when the soil is subjected to shearing action. The shearing action in the soil is influenced by the cohesive forces and internal frictional forces occuring between soil particles. In wet rice soils, failure or yielding of the soil can be evidenced as a plastic flow without shatering and development of shear failures. Increased moisture contents experienced by saturated soils, cause the soil to develop into a lubricative phase where there is a loss in internal friction and a loss in soil cohesion between soil particles (Johnson, 1965). This influences the soil strength and therefore the inability of the soil to support machinery.

Five soil samples from the rice paddy constructed on the Soil Science research field, were analysed in the Soil Science laboratory at MSU. The results of the mechanical analysis using the pipette method are shown in Table 3.

Table 3.--Mechanical Composition of the Soil. Sandyloam (USDA Classification).

	Average % for five Samples
Sand	64.8
Silt	22.3
Clay	11.9

Bates, (1957) indicated that there are three types of wet paddy lands. 1) The clays, with a firm pan or bottom a few inches below the surface; 2) the silt and sandy silts which are hard baked in the dry season and completely water logged in the wet season and do not have a hard pan layer, within the reach of the surface; 3) the peats. The mechanical analysis of the soil samples collected from the field show that the soil in which the tests were conducted belong to the category of sandy loams, as shown by the USDA soil classification.

Analysis of the soil moisture content on the dry weight basis for both the saturated soil as well as the firm soil gave the following results. An average of ten samples for the firm soil condition gave a moisture percentage of 18.9%. The indicated moisture percentage was due to the flooding of the entire field done fourdays earlier, to test the water retention of the field. Several "wet spots", especially where the water pipe was fixed, were noticed.

Table 4.--Average Travel Speeds on Different Surface Conditions for Varying Engine Speeds and Gear Ratios.

Engine Speed	Gears	Travel on Concrete ft/min.	Travel on Firm Soil without Rotovator ft/min.	Travel on Firm Soil with Roto. ft/min.	Saturated Soil without Winch	Saturated Soil with Winch
950	1 low	24	22**	21*	no movement	stalled eng.
	1 high	37	36**	34*	no movement	stalled eng.
	2 low	98	95**	84*	no movement	stalled eng.
	2 high	148	--	--	no movement	stalled eng.
1200	1 low	29	28**	27*	no movement	29***
	1 high	48	47	45*	no movement	47***
	2 low	123	105**	96*	no movement	stalled eng.
	2 high	177	--	--	--	--
1500	1 low	36	35**	33*	no movement	35***
	1 high	58	56**	54*	no movement	56
	2 low		Speeds Too Fast			
	2 high		Speeds Too Fast			

* Significant difference between speed with rotovator and without rotovator: $\alpha = 0.05$

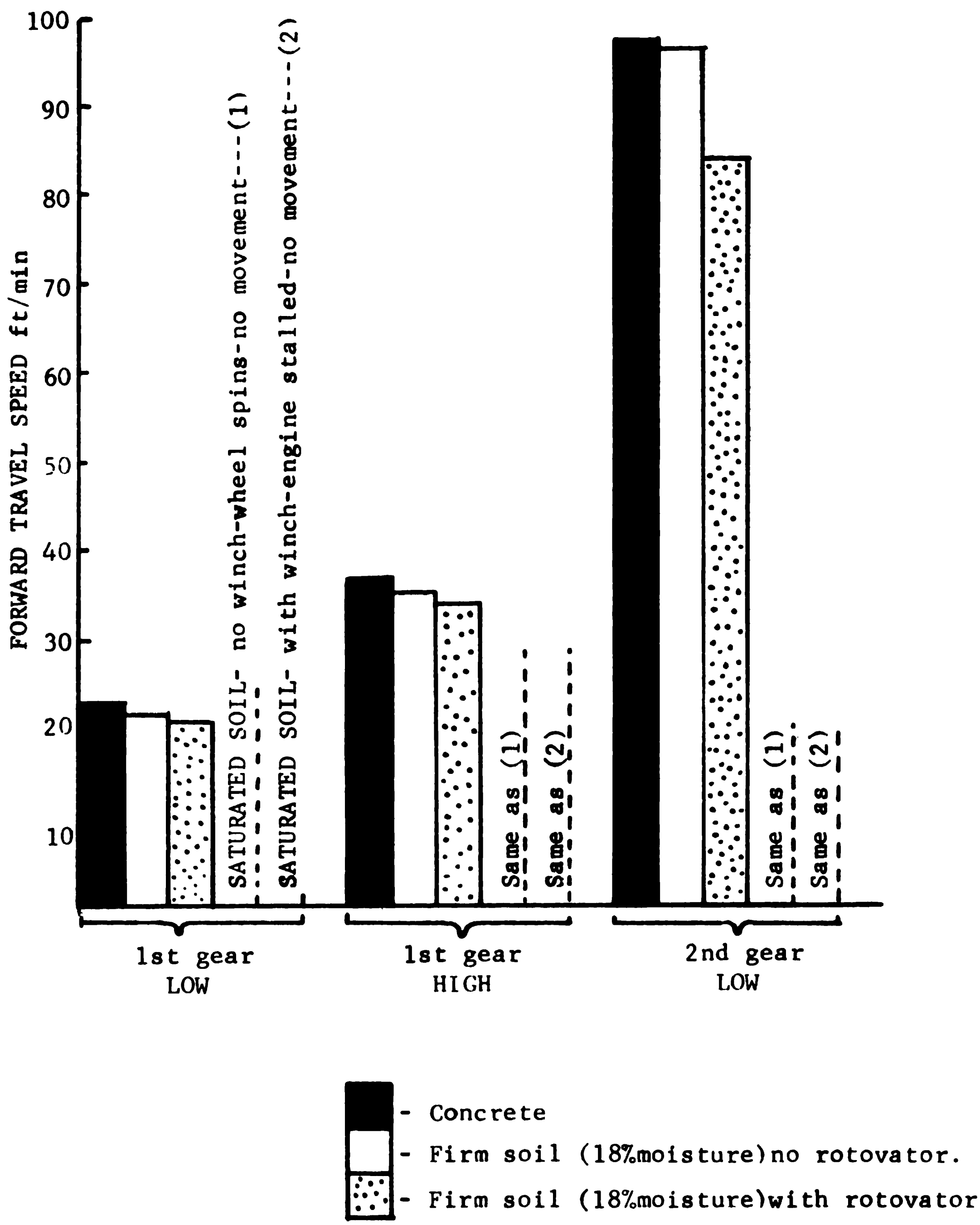
** Significant difference between speed without rotovator and speed on concrete: $\alpha = 0.05$

*** No significant difference in speeds between speed on concrete and speed with winch.

In the saturated soils the average moisture percentage in the rice paddy was 31.7%. Tests with the tractor were performed on both these moisture conditions as mentioned in the Chapter III.

Travel speeds obtained for the concrete surface as well as the four soil conditions and the average speeds for different gears and engine speeds are shown in Table 4. Figure 4.1 represents the speeds calculated at 950 rpm,

Figure 4.1 **Forward speeds for different gears at 950 rpm engine speed, under varying surface conditions.**



engine speed. On the 1^{st} low gear, the average speed on concrete was 24ft/min and exceeded the speed on firm soil without the rotovator (22ft/min) at a significance level of $\alpha = 0.05$ for ten observations. The average speed for the tractor with the rotovator working on firm soil was 21ft/min and was less than the speed for the tractor without the rotovator (22ft/min) at: $\alpha = 0.05$. Therefore the use of the rotovator caused a loss in forward travel speed. The reason could be the distribution of power between the wheels and the rotovator during forward travel. In the condition without the rotovator all engine power was used by the wheels to move the tractor forwards. The travel reduction due to the soil condition was observed as the loss of speed when the tractor was used without the rotovator on firm soil as compared with the speed of the tractor on the concrete surface.

The two wheeled tractor could make no forward movement in the saturated soil of the experimental rice paddy. Excessive slip of the wheels in the mud caused the tractor to bog down. No amount of pushing or pulling by hand as well as an increase in engine speeds could get the tractor to move. A tow rope attached to the truck was used to pull the tractor out of the mud. The rotovator in this condition did not provide enough propulsion to move the tractor forwards. Although it was shown by Khan (1968) that the rotovator provided a pushing force to increase mobility in mud soils, no movement was experienced in these

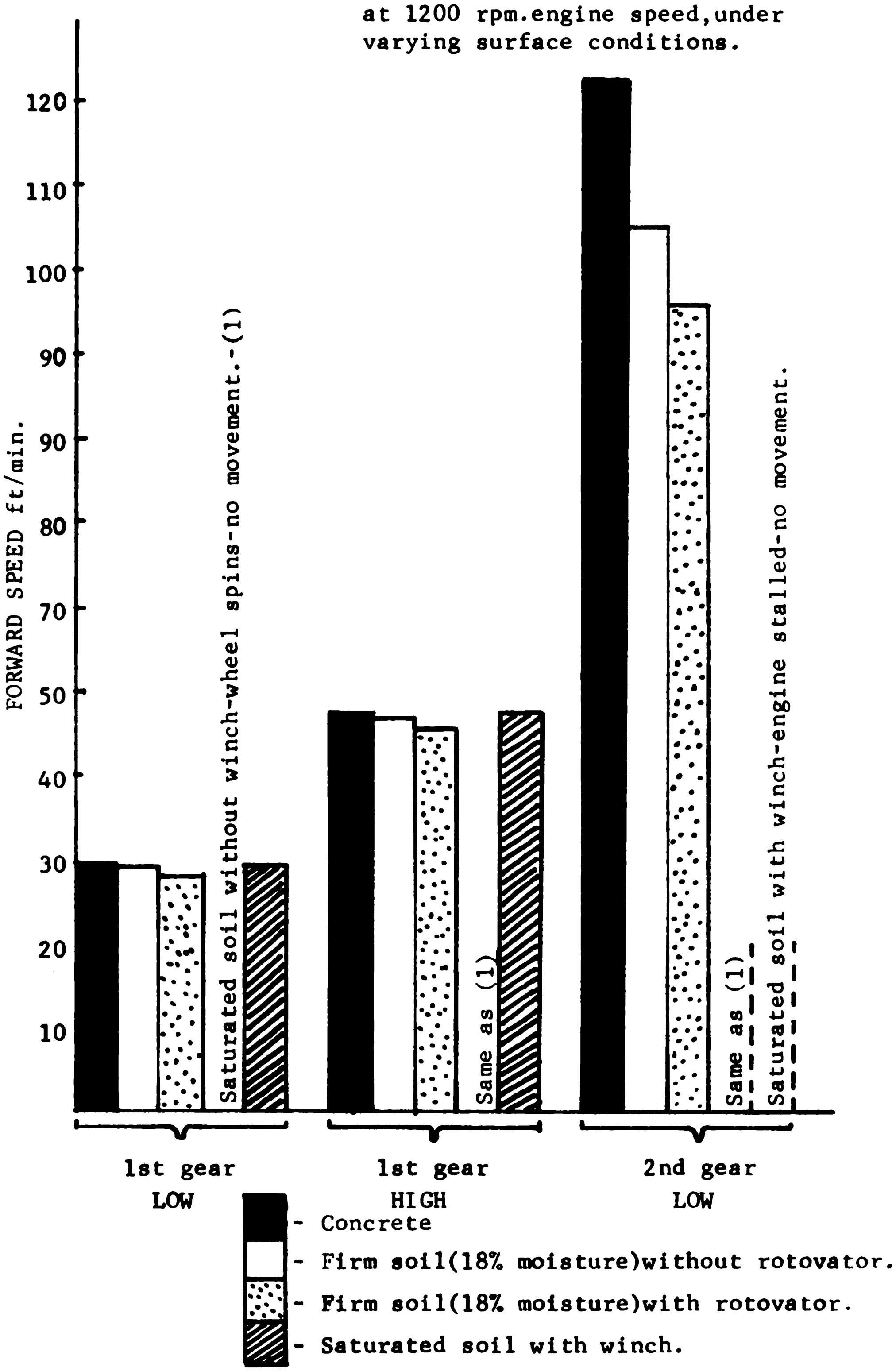
Figure 4.2 The entire winch system was sunk in the mud when the winch was not used to move the tractor in saturated soil.

tests. The reason is that when the tractor bogged down, the front end of the tractor was lowered so that the entire winch system was sunk in the mud (Figure 4.2). This caused the rotovator and the back end of the tractor to lift up. Thus the pushing effect of the rotovator did not help in propulsion, since there was inadequate contact between the blades and the soil.

When the tractor was used with the winch, the power generated by the engine was insufficient at this low speed and caused the engine to stall and stop. Similar conditions were seen to take place in the 2nd low gear.

Figure 4.3 represents the forward speeds calculated for 1200 rpm engine speed. On the 1st low gear the speed

Figure-- 4.3 Forward speeds for different gears at 1200 rpm.engine speed,under varying surface conditions.



on concrete was 29ft/min and exceeded the speed on firm soil without the rotovator (28ft/min) at a significance level of $\alpha = 0.05$, for ten observations. The average speed for the tractor with the rotovator was 27ft/min and less than the speed for the tractor without the rotovator (28ft/min) at: $\alpha = 0.05$. Adhesion of mud on the small lugs of the wheels especially in the "wet spots" could have affected the average speed on both conditions, with the rotovator and without the rotovator on firm soil. Similar reductions in travel speed for the tractor without the winch as those for the engine speed of 950 rpm were experienced at 1200 rpm. The tractor refused to move in the saturated soil, without the winch system. The tow rope attached to the truck was used to pull the tractor out of the field.

At 1200 rpm the winch was able to pull the tractor through the saturated soil in both high and low 1st gear. The speed on the 1st low gear averaged 28 ft/min. The tractor travelled with the least effort on the part of the operator similar to the movement on firm soil. A slight side draft to the right was experienced. This was due to the pulling point of the rope not falling exactly on the central axis of the tractor. The draft could be eliminated (in future designs) by moving the winching system to the right, so that the center of pull would fall exactly on the central axis of the tractor. The movement of the tractor through the saturated soil illustrated a positive action by the winch in pulling the tractor through the saturated soil and thereby increasing its mobility. Similar observations were made for the 1st high gear where the average forward speed of the tractor with the winch system was 48ft/min, equal to the average speed on concrete (48ft/min) There was no significant difference between the speeds on the concrete surface and that of the winch condition, at a significance level of $\alpha = 0.05$ for ten observations. On the 2nd low gear there was no movement in the saturated soil with the winch system. The engine stalled and did not allow the winch to perform its pulling action.

Figure 4 4, represents the forward speeds at 1500 rpm engine speed. On the first low gear the speed on concrete was 36ft/min and exceeded the speed on firm soil with the rotovator (35ft/min) at a significance level of $\alpha = 0.05$. The speed of the tractor with the rotovator on firm soil was 34ft/min and less than the speed of the tractor without the rotovator (35ft/min) at $\alpha = 0.05$. Similar observations as those for 950 rpm and 1200 rpm were noticed for the saturated condition with and without the winch system. With the winch system in the 1st low gear the tractor moved at an average speed of 36ft/min which was equal to the average speed on concrete (36ft/min). There was no significant difference between these two readings at $\alpha = 0.05$ for ten observations. On the 1st high gear the average speed with the winch was 56ft/min and less than the average speed on concrete (58ft/min) at $\alpha = 0.05$. No readings were attempted on the 2nd low and high gears as in

Figure.-- 4.4 Forward speeds for different gears at 1500 rpm engine speed under varying surface conditions.

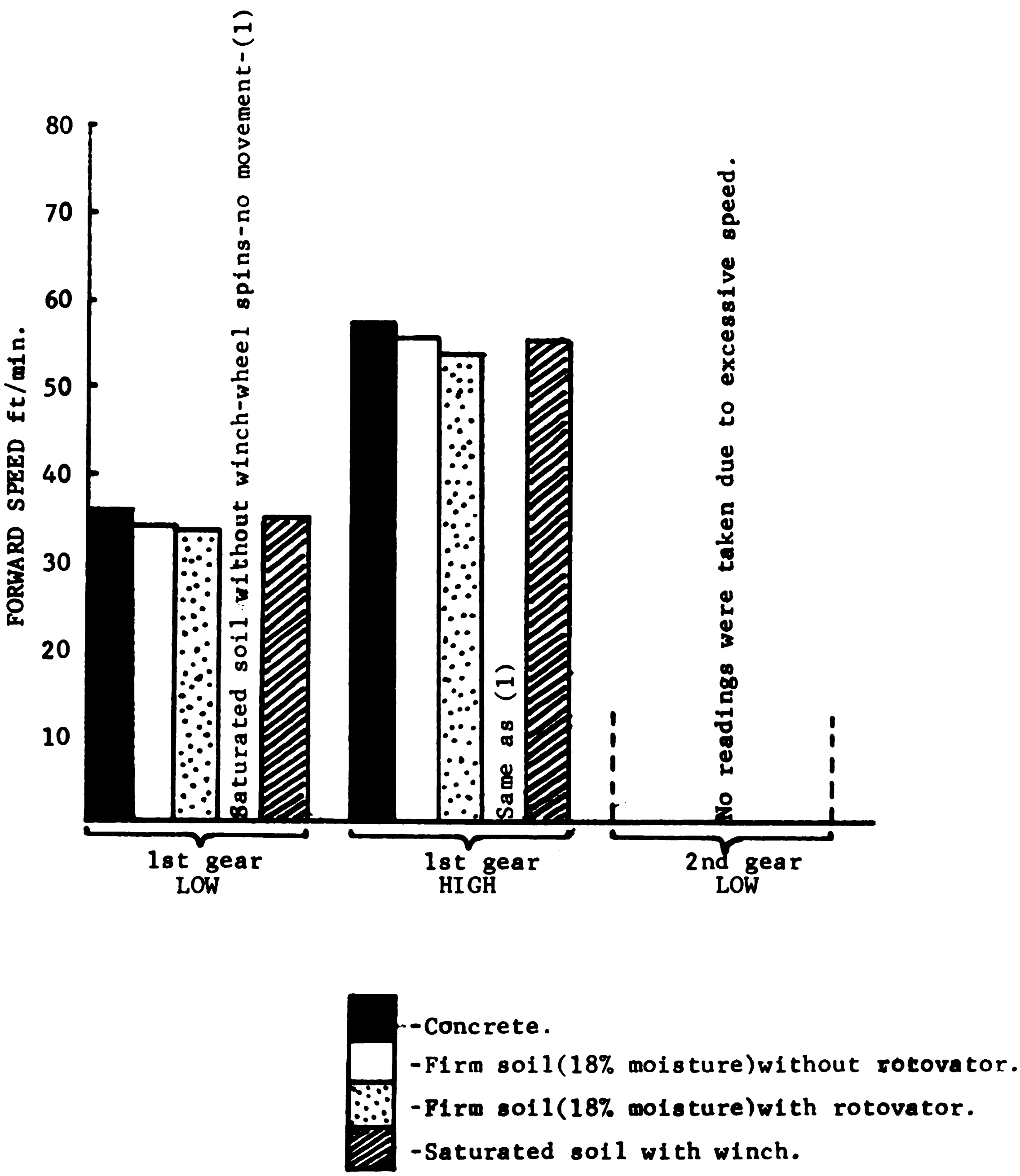


Table 5.--Pull Generated by the Winch for Different Travel Speeds in Saturated Soil.

Engine Speed	Pull in lbs 1st low Gear	1st high Gear	Hp Hp 1st low Gear	Hp 1st high Gear
1200rpm	797	480	0.67	0.70
1500rpm	580	381.5	0.63	0.66

this gear the speed is excessive for comfortable operation of the tractor.

Table 5. shows the average readings that were observed for the pounds pull on the end of the rope, measured by the spring dynamometer. Draft readings were taken for every 20 feet run made by the tractor operating in the saturated soils. The readings for 1200 rpm engine speed on the first low gear averaged 797lbs and was 39% higher than that observed for the first high gear which averaged 480lbs. Similar reductions in lbs pull were observed in the higher engine speed of 1500 rpm, 580lbs for the first low gear and 381.5lbs for the first high gear. Figure 4.5 shows the drop in pounds pull exerted through the winch for the various travel speeds recorded. The explanation for the reduction in pounds pull is that the rotovator and the wheels provided a forward thrust to the tractor that is more effective at higer speeds. Therefore an increase in push is given by the wheels and the rotovator, causing a reduction in the pull exerted through the winch.

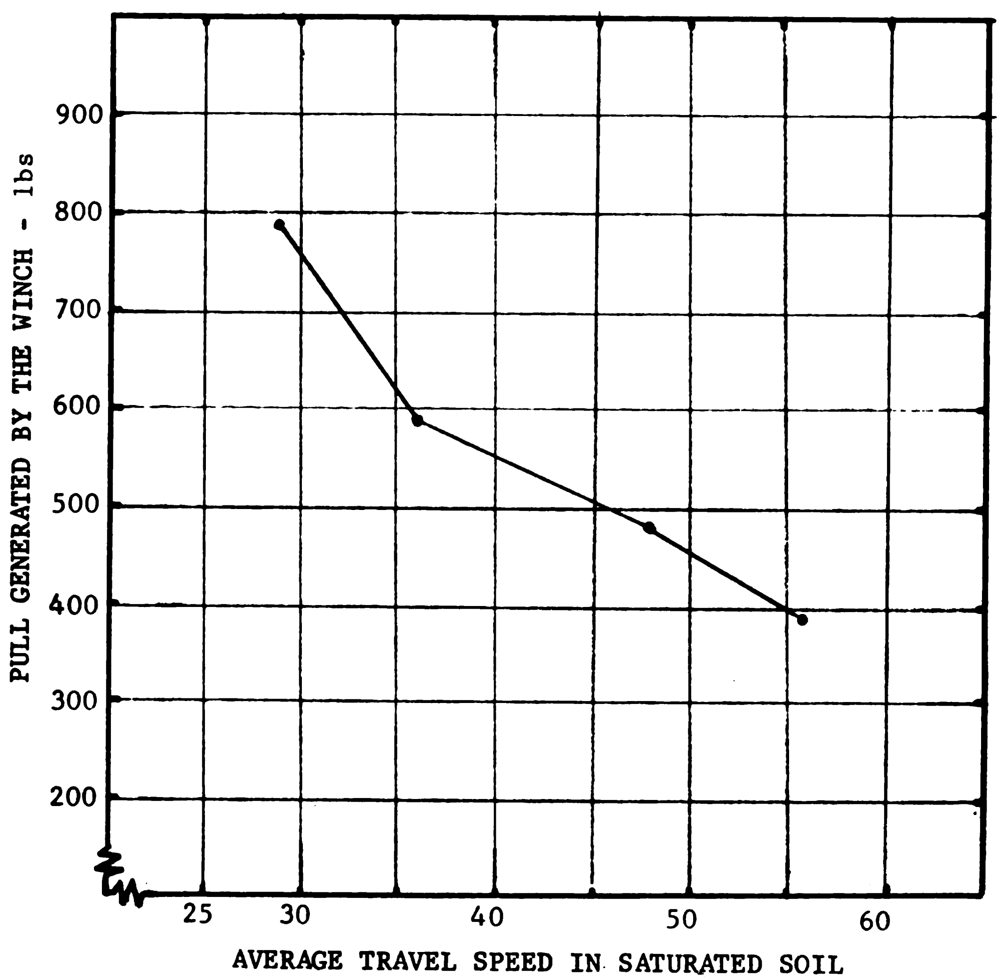


Fig.(4.5)Pull generated by the winch for different travel speeds in saturated soil.

Figure 4.6 The front end of the tractor was lifted when the winch system was used.

Figure 4.6 illustrates the rotovator moving downwards into the soil when the winch was used as compared with the lifting of the rotovator without the winch use, thus providing better rotovator blade-to-soil contact, and improving its ability to provide extra propulsion. The use of the winch also provides a "cleaning" effect on the wheel lugs, thereby causing a better traction surface for the wheels. The combined "push" of wheels and the rotovator with increased speed, and winch use seem to result in a general improvement in traction efficiency and ability of the tractor to move through difficult situations.

Table 6.--Percent Loss in Travel Speed for the Different Test Conditions.

Engine rpm	Gear	% Loss on Firm Soil without Rotovator	% Loss on Firm Soil with Rotovator	% Loss on Saturated Soil with Rotovator	% Loss on Saturated Soil with Winch
950	1 low	7.2**	10.7*	100	stalled eng.
	1 high	4.9**	7.4*	100	stalled eng.
	2 low	2.3**	13.9*	100	stalled eng.
	2 high	--	--	--	--
1200	1 low	2.4**	5.1*	100	.7***
	1 high	1.9**	4.9*	100	.3***
	2 low	14.2**	21.8*	100	--
	2 high	--	--	--	--
1500	1 low	4.0**	6.8*	100	1.0***
	1 high	3.9**	7.2*	100	2.8

* Significant difference at $\alpha = 0.05$ between % loss with rotovator and % loss without rotovator.

** Significant difference between % loss without rotovator and % loss on concrete. $\alpha = 0.05$ for ten observations.

*** No significant difference at $\alpha = 0.05$ between % loss on concrete and % loss with winch.

4.2 Efficiency of Forward Travel

Definite losses in travel speeds can be calculated from the data observed, taking the different test situations into consideration. It is possible to determine a percentage loss in forward travel speed between the test on concrete and other conditions. The travel speed on concrete is then taken as a condition of minimum slip or minimum loss in travel speed. Table 6 shows the % loss in travel speeds for the different engines and gear speeds. Figures 4.7 - 4.9 illustrate the percentage losses in travel speeds.

A better and a more positive representation of the

Table 7.--Efficiency of Different Test Conditions in Relation to 100% Efficiency on Concrete.

Engine rpm	Gear	% Efficiency on Firm Soil without Rotovator	% Efficiency on Firm Soil with Rotovator	% Efficiency on Saturated Soil without Winch	% Efficiency on Saturated Soil with Winch
950	1 low	93.0**	86.2*	0	stalled eng.
	1 high	96.1**	92.6*	0	stalled eng.
	2 low	97.7**	86.1*	0	stalled eng.
	2 high	--	--	-	--
1200	1 low	97.6**	94.9*	0	99.3***
	1 high	98.1**	95.1*	0	99.6***
	2 low	85.8**	78.2*	0	--
	2 high	-	-	-	--
1500	1 low	95.9**	93.2*	0	98.9***
	1 high	97.1**	93.2*	0	97.1

* Significant difference at $\alpha = 0.05$ between % efficiency without rotovator and % efficiency with rotovator.

** Significant difference at $\alpha = 0.05$ between % efficiency on concrete and % efficiency without rotovator.

*** No significant difference between % efficiency on concrete and % efficiency with the winch at $\alpha = 0.05$.

efficiency of the system can be made by taking the speed on concrete as a condition of 100 percent efficiency in forward travel. This would enable the determination of the efficiency of a particular soil condition in relation to its forward speed. Table 7 shows the rate of efficiencies obtained for the different test conditions.

Figure 4.10 represents the efficiencies obtained for the travel speeds. In saturated soils without the winch, the graph shows a line across the zero efficiency line for all speeds. When the winch is used, the range of efficiency varies from 99.6% to 97.1%. When compared with

Figure.--4.7 % loss in forward travel speed taking zero loss on concrete. The tractor is operated at 950 rpm engine speed for varying soil conditions.

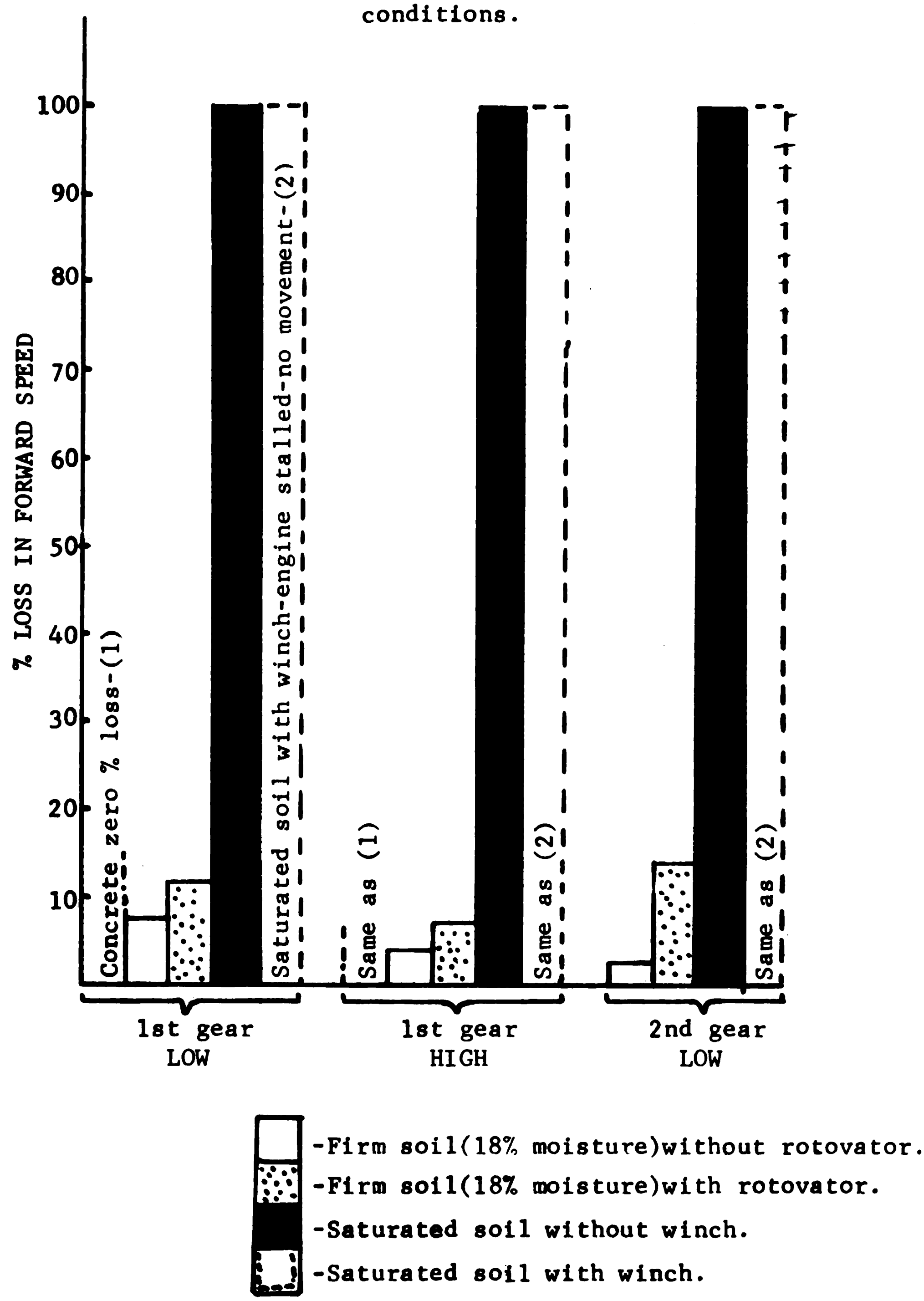


Figure.-- 4.8.% loss in forward travel speed taking zero loss on concrete. The tractor is operated at 1200 rpm engine speed for varying soil conditions.

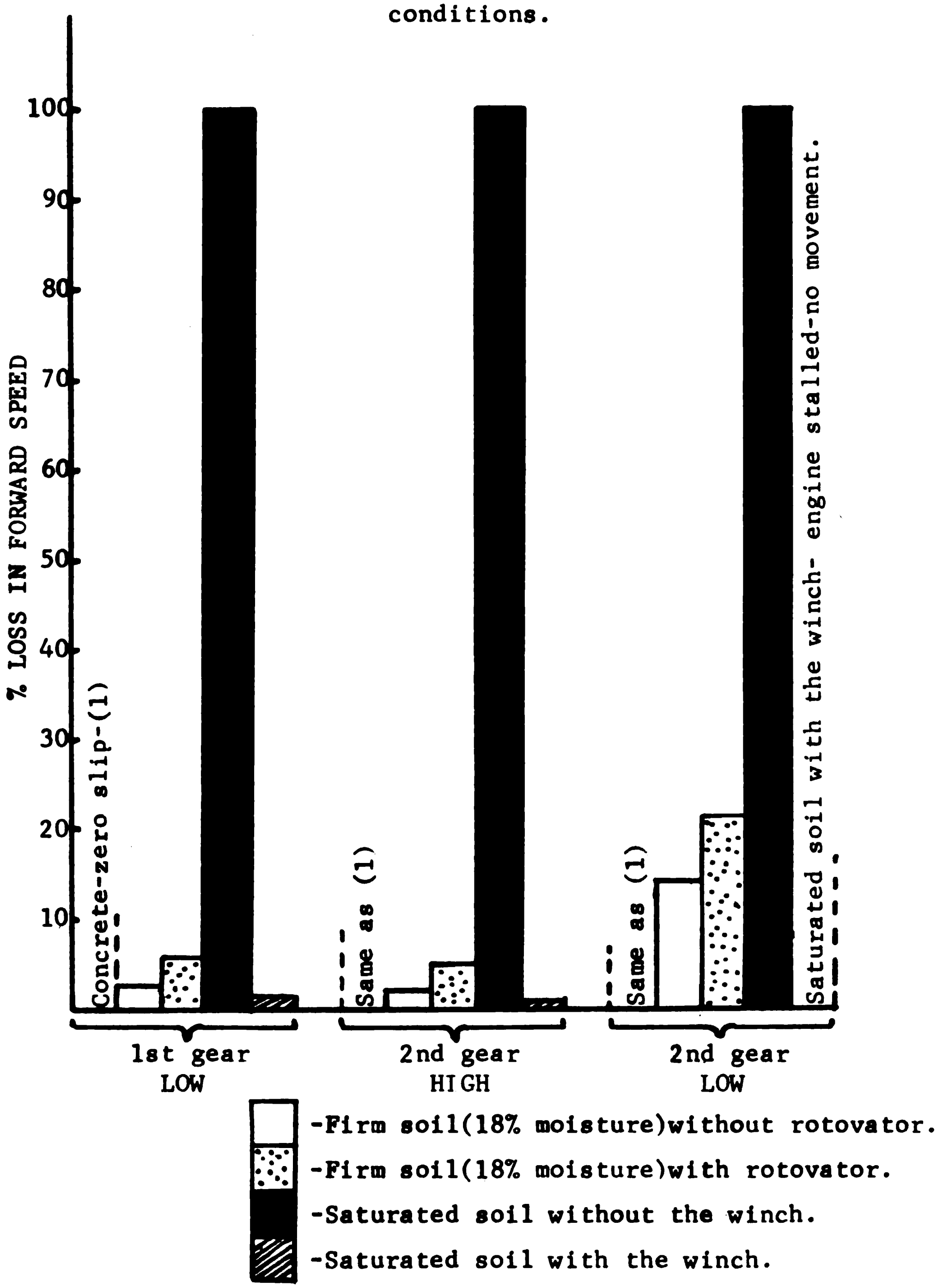
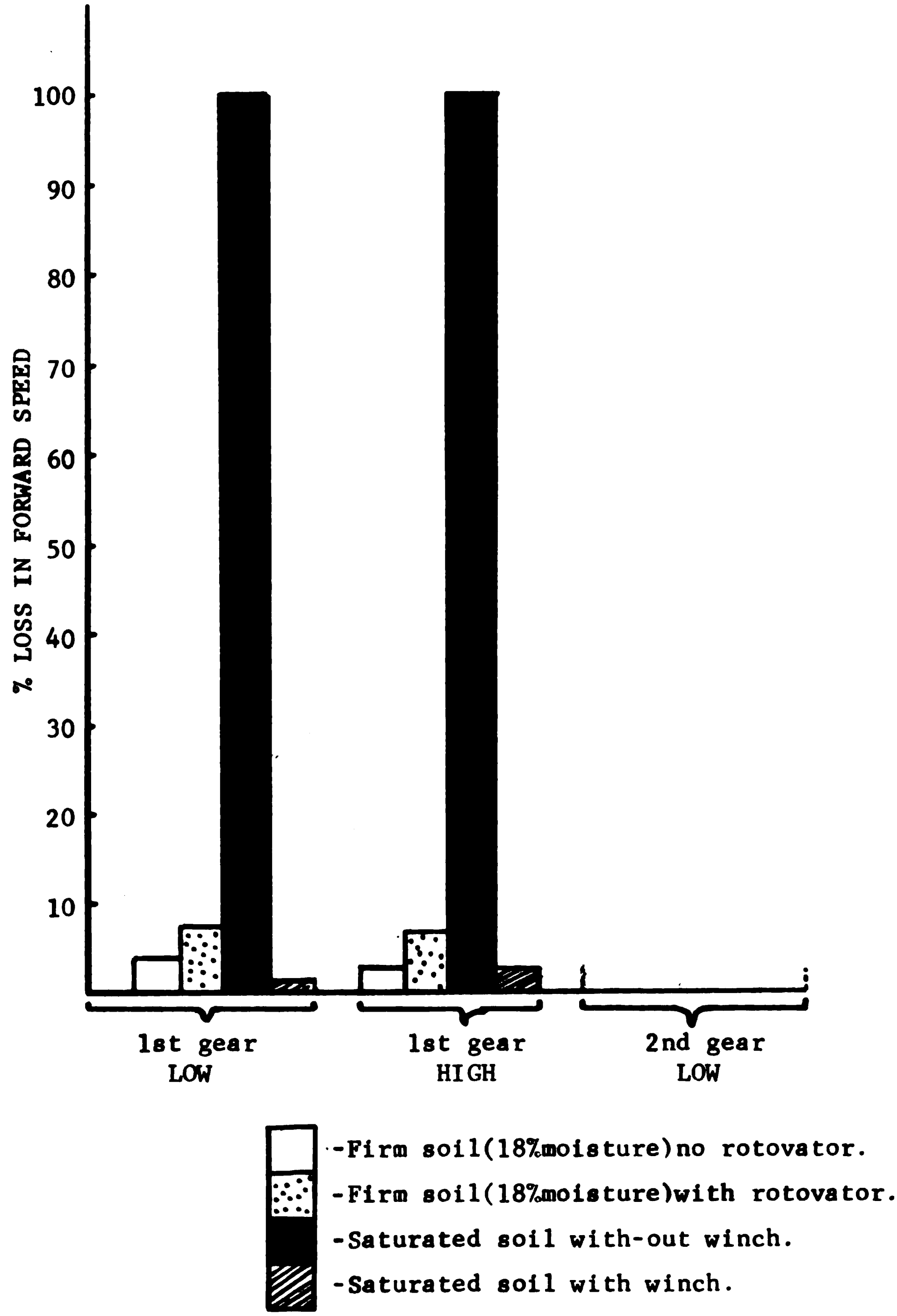


Fig. 4.9 % Loss in forward travel speed taking zero loss on concrete. The tractor is operated at 1500 rpm.engine speed for varying soil conditions.



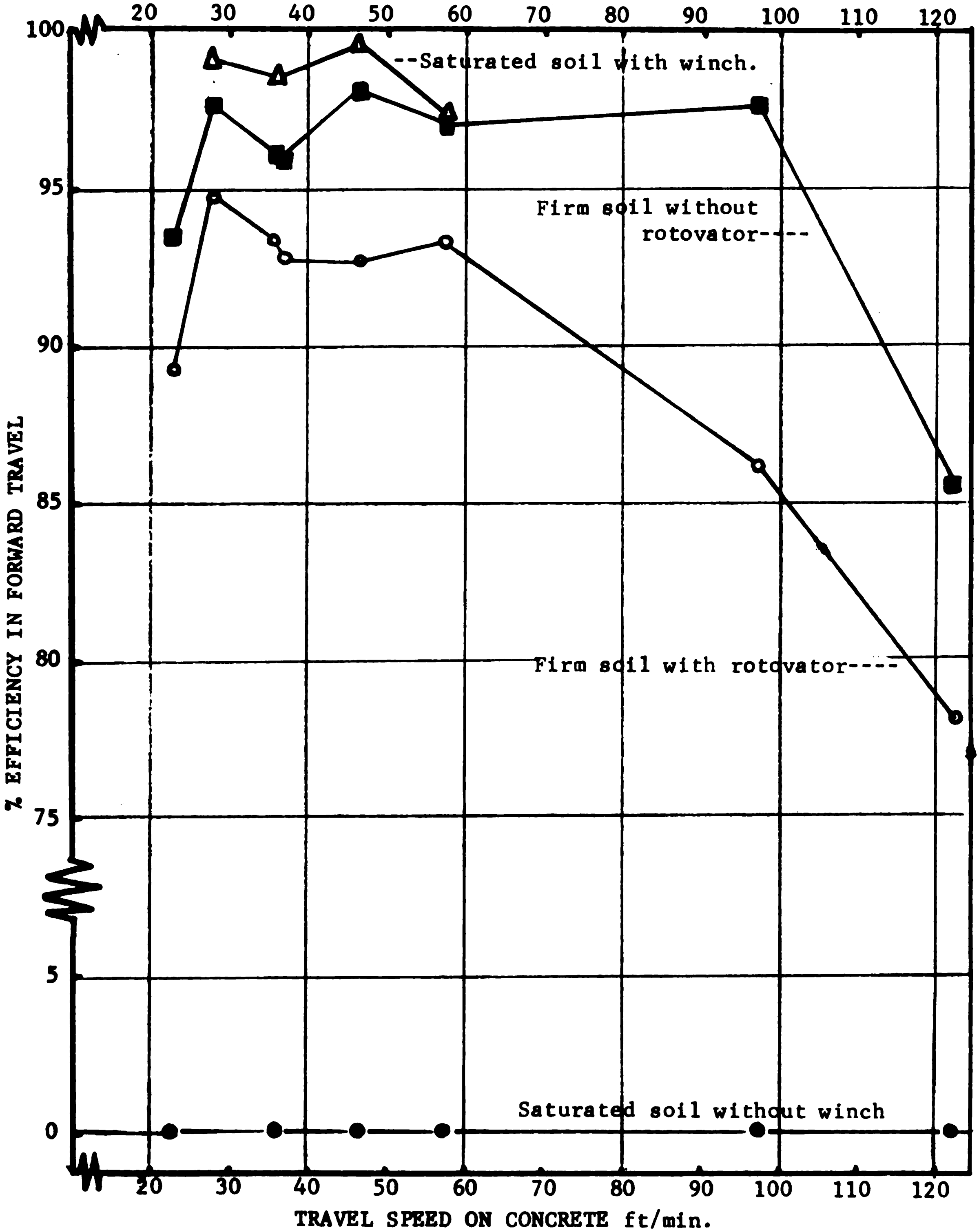


Figure.-- 4.10.Efficiency in forward travel for varying forward speeds. The speed on concrete is taken as 100% effecient.

the test conditions on firm soils as well as tests in saturated soils without the winch, the winch system showed a marked improvement, for traction efficiency. Thus mobility is maximized by the use of the winch.

4.3 Analysis of the Winch System

Sinkage of the tractor as seen in the tests without the winch is typical of that experienced in the saturated paddy soils in Sri Lanka. The lower soil strength of saturated soils is unable to bear the weight of the tractor. The prolonged slipping of the wheels reduces soil shear strength further and makes the tractor sink deeper into the soil.

Adhesion of the mud filling inbetween the lugs of the wheels cause a smooth surface to develop. This makes the lugs on the wheels ineffective. Traction is therefore limited and the wheels do not provide the necessary power transmittal to the soil to bring about forward propulsion. The wheel diameter and width of the test tractor is small compared with the conventional large diameter paddle wheel and therefore hindered the forward movement of the tractor. Domier (1967) showed that larger diameter wheels increased traction efficiency on various agricultural soils. In typical saturated rice soils of most Asian countries, large paddle wheels replace the pneumatic tires to aid in traction. The floatation effect provided by the paddles helps in keeping the tractor from sinking by aiding power transmittal but still does not completely eliminate slipage of the wheels. A test with this type of wheel would help in gaining better forward movement in the saturated test condition, compared to the zero movement observed. The fact that the paddy field was plowed and harrowed before actual field tests were done, caused the strength of the soil to be reduced when saturated compared with a field with stubble left from a previous crop. The soft soil in this test is quite an exageration of the conditions normally experienced, where crop residues are present during initial land preperation. The stubble of crops, increases the soil strength and trafficability of the tractor in the soil. Further studies of the winch system would be desirable to determine its efficiency where actual crop residues exist on the land during the tests.

The use of the roto-tiller did not help in forward movement under these test conditions. In tests conducted on large four wheel tractors in the International Rice Research Institute, it was found that an adjustable 155cm wide x 90cm diameter, 8 blade rotary tiller at a blade angle of 32.5° gave a push of 300 to 900kg at a tilling depth of 10cm (Kahn, 1968). The test performed with the two-wheel tractor in this study showed no assistance from the rototiller for forward movement. The reason is that without the winch action the added weight of the winch mechanism caused the front-end of the tractor to tip downwards into the soil, lifting the back, causing little contact between the soil and the blades for forward propulsion. This combined with the fact that since there was little help given for forward movement by the spinning mud coated wheels, the tractor could not provide the necessary traction to move forward.

The attachement of the winch to the tractor as a traction aid provided a positive improvement in trafficability. The winch enabled the tractor to pull itself on the rope through the field. Without the winch, it was impossible.

The most significant advantage seen from using the winch system is that the traction aid is entirely independant of the soil condition as compared to the conventional traction aids. The earlier developed innumerable traction aids such as the cage wheels, extendable lugs, hollow steel wheels with steel lugs, crawlers half-tracts etc; all depends on the surface texture, soil shear strength and condition of the soil for its performance. Stout, (1966) indicated that different methods are needed for supporting machinery and tractors for different soil types. Penetration by means of special lugs and extentions on the wheels are made for clay soils so that they could reach the "bottom". Floatation devices are sought for the peats, to keep the equipment on the surface of the soil by using wide and large diameter wheels or long tracts. These wheels distribute the weight over a larger area as possible. The winch system however does not depend on the soil, and therefore is applicable in any soil type.

The winching system is directly connected to the PTO drive of the tractor by a positive chain drive. Therefore it pulls the rope at a forward speed approximately equal to that found on concrete (Table 4). Slip of the rope on the winch surface causes the loss in speed observed. On the 1^{st} low gear at an engine speed of 1200, the loss in forward speed is 0.7%, showing that there is an efficiency of 99.3% in moving the tractor forwards, compared to the 100% mark on concrete. A better value of 99.6% is seen on the higher gear indicating a forward propulsion provided by the wheels and the rotovator. A higher loss was experienced in the 1^{st} low and high gear 1.0% and 2.8% respectively, at an engine rpm of 1500. A higher loss could be attributed to the slip of the rope at this speed. The rope at this stage of testing was extremely wet, and could have resulted in slipping due to the lubricative effect of the water; but in comparison to the 100% loss in forward speed experienced in saturated soils without the winch, this was indeed a tremendous improvement.

Figure 4.6 shows that the tire lugs are no longer packed with mud when being pulled forwards with the winch system. The winching action and resulting motion seem to cause a "cleaning" effect of the tires, thereby exposing the lugs. Traction by the tire is thus improved.

From the pounds pull observed at the different engine speeds, Table 5, the average horsepower developed by the winch in pulling the tractor was found to be .69

for 1200 rpm and .64 at 1500 rpm. A significant difference between the hp at 1200 rpm and hp at 1500 rpm for the ten observations was shown at $\alpha = 0.05$. A significant difference in hp was also observed between the low and high gears at the respective engine rpms. at: $\alpha = 0.05$. An average of .67 hp is used up by the winch in pulling the tractor out of the muddy conditions, at the working engine rpms. The independant nature of the winch in regard to the soil conditions, is the reason for the very low hp rate observed. Since no slip or rolling resistence is experienced by this traction aid, the only work it has to perform is to pull the tractor forwards, aided by the propulsion of the rotovator blades and the wheels. Further research should determine the actual hp distributions between the winch, rotovator and the wheels in the saturated condition, so as to determine the energy consumption of such a system as against that of the tractor with out the winch, in saturated soils. This would give a better understanding of the power efficiency of the winch system as a whole. Winter weather and freezing soil prevented these additional tests.

Use of steel paddle wheels with the winch system, or increased diameter wheels in further tests may also provide significant results as to the efficiency of the system in the given saturated conditions.

4.4 Application of the System

Field sizes for rice cultivation in saturated soil are small. A one acre rice field would normally be divided into quarter acre blocks or smaller. Therefore anchoring of the rope to a point outside the field could easily be done by the operator. In most Asian countries labor is abundant. It is very common to see numerous people watching a tractor working in the field. Making use of labor to attach a rope to an anchor point would not be a problem, especially in family farms where family help is available.

Figure 4.11 represents a proposed method of application for the designed winching system, on a land area 40ft wide and 100ft long, using a tractor having a working width of 3 feet. This system would make use of the operator to anchor the rope on to the edge of the field. The stakes are represented by a * on the field in Figure 4.11. These would be the anchor points. They could be either temporary fixtures or be permanent, in which case they may be used for all cultivation seasons there-on. The latter is preffered. This prevents excess use of time for driving the stakes into the ground. The proposed plan is for permanant stakes. The stakes could be either made of strong wood with a ring attached to it, or made of steel. The construction of the stake would depend on the maximum pull exerted by the winch. A hook attached to either end of the rope would help in hooking the rope to the ring on the stake, saving time on the tying operation.

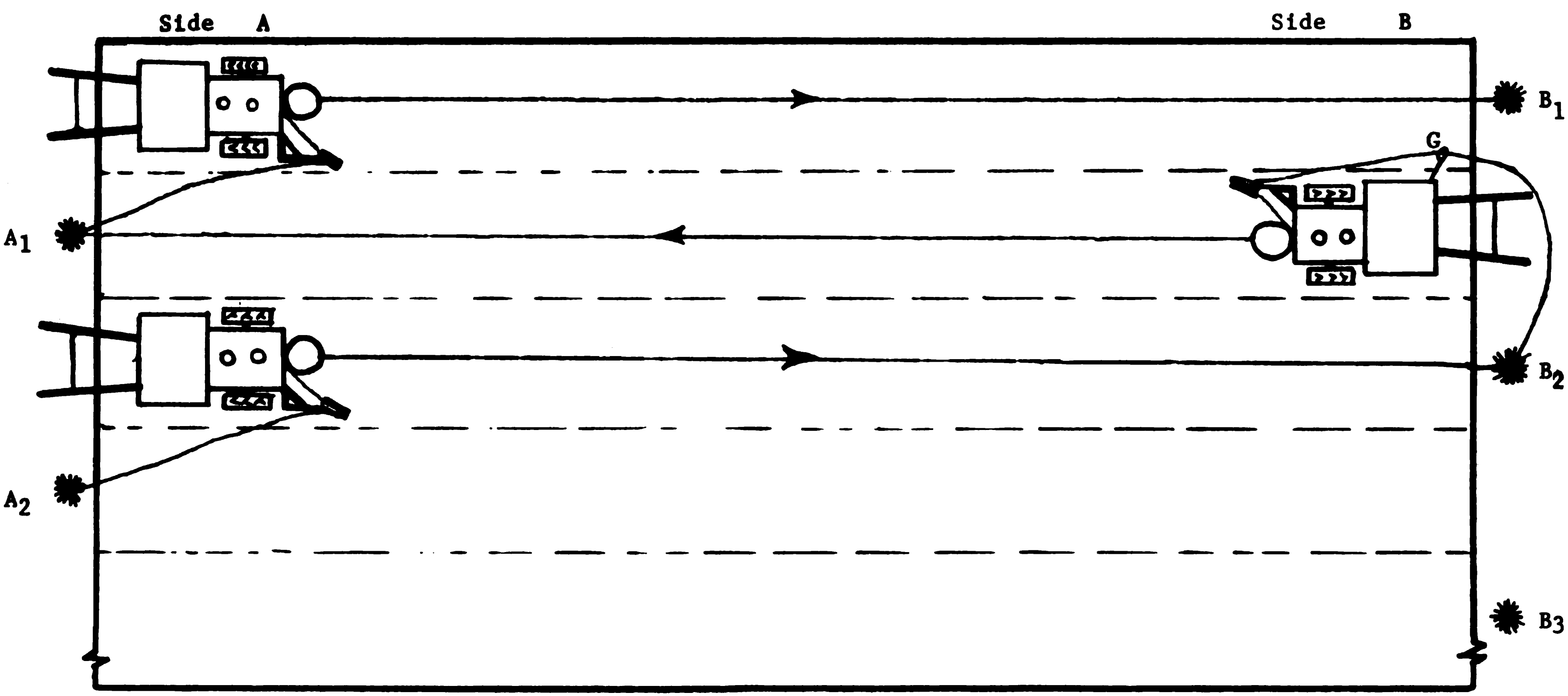


Figure.-- 4.11. Schematic for the proposed application of the winch system.

The tractor in this design could start on either side of the field, puddling the soil progressively to the right of the field or progressively puddling the soil to the left of the field. The rope coming out of the take-up pulley is slack and therefore does not need any tension. Figure 4.11 shows the tractor unit attached for its first movement to the side B of the field. The rope from the take up is attached to A_1 on side A of the field. When the operator has moved to B by pulling on stake B_1, he removes the rope from B_1 and then from the winch, by unwrapping it from the bottom of the winch and pulling it out from the take-up pulleys. The tractor is then turned and ready to move towards A by pulling on the rope attached to A_1 at the begining of the operation. The rope removed from B_1 is wrapped around the winch system, and sent through a rope guide (G) on the tractor and fixed onto the anchor B_2. The guide prevents the rope getting entangled with the tractor and the rotovator at any time during the operation. There will be plenty of slack on the rope going through the guide to B_2, as no tension is required for the rope leaving the take-up pulleys. When the operator moves to A_1, he removes the rope on A_1 and unwinds the rope on the winch system. The tractor is then turned to face B. The operator winds the rope around the winch system and attaches the end to A_2. The tractor is then moved across the field by pulling on anchor B_2. This process is repeated till the end of the field is reached.

V - CONCLUSION

The following conclusions were arrived at, based on the evidence of the tests performed.

1. The Capstan winch drum attached to the tractor assembly provided a steady pulling motion through the rope without rope wrapping or excessive slip.

2. Reduction in travel speeds were observed on firm and saturated soil, as compared with the speed on concrete.

3. No forward movement of the tractor was possible without the winch in the saturated test soils, due to unlimited wheel slip and sinkage.

4. The rotovator did not provide the traction assistance in the winchless condition, to help move the tractor in saturated soil.

5. The winch provided a positive pulling force to move the tractor through the saturated soil.

6. The winch system showed positive results as a traction aid to increase mobility in rice fields, the objective of the project was justified.

VI - RECOMENDATIONS FOR FURTHER STUDY

1. Determine the efficiency of the system as regards to its power distribution and energy consumption between the winch, rotovator and wheels, compared with the energy lost in working the tractor without the system.

2. Repeat tests performed, by attaching a conventional traction aid in place of the pneumatic wheels, and compare its efficiency with that of the winch.

3. Repeat tests without the rotovator to determine the pushing effect of the rotovator when the winch is attached.

4. Perform similar tests, varying the soil conditions in relation to the presence and absence of crop residues and determine the respective efficiencies of the system.

5. Design and construct an anchor point to withstand the pull exerted by the winch.

6. Evaluate the entire system as to its efficiency in relation to, energy use, time study effective use of abandon land, and its economics.

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