Chapter 2

Review of Literature

This chapter deals with the review of the past research works conducted by the scientists in the field of evaluation and control of slip in the tractive devices. Accurate methods to measure the slip is difficult task when the tractor is under operations in the field. Slip indicators are not provided even in the latest development of tractors although the same is a very critical requirement. For optimizing the performance of a tractor, slip is an essential parameter at the operating load. Efforts have been made in this chapter to study, analyse and review the works conducted for the computation of slip by different scientists to maximize tractive efficiency (TE). It is apparent from the relevant studies that slip measurement can be brought under two groups. One in the laboratory and the other under actual field conditions. Research methods are followed when accuracy is very essential. Tractors were suitably modified before the conduction of lab experiments, whereas, field measurement method does not require modifications. Literature indicates that complex mechanism is involved in the research projects for the computation of slip. Most of the methods are involved for the measurement of linear velocity.

The major discussions in the field of slip measurements are presented below.

- Slip measurement techniques
- Depth measuring methods
- Draft measurement methods
- Influence of slip on performance
- Draft control mechanism
- Slip control mechanism
- Effect of soil salinity on slip
- Effect of Soil moisture on slip
2.1 Slip Measurement Techniques

Two major processes are followed for the measurement of slip

1. Manual method

2. Automatic method

2.1.1 Manual method for the Measurements of Slip

There are two possible methods for measuring slip manually.

(a) **Fixed distance method** :

As per this method, the revolution of wheels are counted for covering a fixed distance, the nos. of revolution of wheels are counted. The same is carried out either with load or without load condition depending upon the requirements.

\[
S = \frac{N_1 - N_0}{N_0} \times 100 \tag{2.1}
\]

where,

\[N_1 = \text{number of revolutions of drive wheels with load;}\]

\[N_0 = \text{number of revolutions of drive wheels with no load;}\]

(b) **Fixed revolution method** :

In this method, the distance covered by the wheels is considered for fixed number of rotations. This test is also conducted with and without load.

\[
S = \frac{d_1 - d_0}{d_0} \times 100 \tag{2.2}
\]

where,
\[ d_0 = \text{distance travelled in fixed number of revolutions with no load.} \]

\[ d_i = \text{distance travelled in fixed number of revolutions with load condition.} \]

As the distance measurement is easier, fixed revolution method is widely accepted.

### 2.1.2 Automatic Slip Measurement

Manual measurement of slip is not only a difficult task during field operation but the accuracy is also not consistent. For measurement of on line wheel slip, there is a necessity to use automatic measurements method. Many researchers felt the necessity of online measurement of slip for which the automatic method is the only solution. For the performance measurement of tractors, continuous data is necessary which is possible only through automatic measurements. Online slip sensing and control process serves as a source of information for the driver while doing the field operations to control the slip within optimum range for achieving maximum TE.

Farther and Schafer (1969) automated the slip computation by using an analog computer. In their experiment, slip measurement was done continuously during field use of tractors. Although the evaluation of the slip was performed by the computer, there was a necessity for setting the initial value of slip. Unlike present situation, the full capability of computer was not utilized by them. Setting of initial value of slip was dependent on some assumptions and experiences of the driver which differed from individual to individual. Two major disadvantages were observed in this procedure for which the instrument was not so popular.

(a) The full capability of computer was not explored and was used in a small scale.

(b) The initial setting was to be done manually. The manual setting of values caused undesirable errors due to assumption and approximations.

A different technique was developed for automatic measurement of slip by Lyne & Meiring (1977) who used photo electric transducer for sensing the revolution of wheels of tractor. They made arrangements for the display near the dashboard of the tractors to guide the drivers about the measured slip value so that driver could adjust the control
levers to maintain slip within optimum range to obtain maximum efficiency. The instrument was capable of the online slip measurement with display and recording facility. The measurement system using photo-electric transducers performed accurately within 1-2% over the entire range of normal operating speeds. The speed of the front wheel was chosen for surface velocity calculation. In this method, the speed of both the front wheels was monitored and the faster of the two was considered for calculation purpose. For slip calculation, the front wheel velocity was considered as actual velocity and the drive wheel velocity was considered as theoretical. The percentage difference between the two velocities was indicated as slip. This was achieved by comparator circuits. It was observed that there was error in ground speed calculation in Lyne & Meiring method which resulted in occurrence of error in the slip calculation. Hence, the instrument was not adopted commercially.

A non-contact method was developed by Thansandote et al. (1977) with modern solid state MW Doppler radar for ground speed and RPM measurements. Radar sensor works in the principle of Doppler effect. The MW frequency focused to the surface gets reflected with a different frequency. According to the Doppler effect, the difference of the frequency between the radiated and reflected signal is proportional to the speed of the vehicle where the sensor is installed. The method for slip measurement with Doppler radar instrument had higher accuracy. Although the accuracy was high, the system could not be put to commercial use as the cost of the radar sensor is quite high and not affordable by tractor operators.

In order to achieve better accuracy of the slip measurements, Grevis-James et al. (1981) designed a power monitor. The monitoring system included magnetic transducers, display system, associated circuitry for detection of ground speed, drawbar pull, drawbar power and wheel slip. For ground speed measurement, one of the front wheels was considered. In case of a 4WD tractor, a 5th wheel was attached for the measurement of surface speed. A magnetic pick up device was deployed with an amplifier to boost the pickup voltage up to 6 V. The reliability of the developed instrument was satisfactory.

Tompkins & Wilhelm (1982) developed a system which incorporated a DAS for computation of slip in a tractor. A 5th wheel was attached for the surface speed
measurement. To facilitate the same, a magnetic sensor and 72 geared wheel assemblies was mounted with the rear axle.

\[ S = \frac{V_r - V_f}{V_r} \times 100 \]  

...(2.3)

where, 

\[ S = \text{wheel slip;} \]

\[ V_r = \text{voltage from the rear wheel sensor} \]

\[ V_f = \text{voltage from the front wheel sensor} \]

Grogan (et. al 1987) developed a microcomputer based system to compute the slip of 2WD traction device. The same system was also used for optimization of tractive performance through necessary guidance system for the driver. By setting the throttle and gear optimally, the consumption of fuel was reduced by about 15-27%

Jesurajan (1988) developed a device containing of photo electric transducer to sense the speed of the front and rear wheels. The unit had an up/down counter with a digital display unit. Reference was obtained from the fifth wheel for speed measurement purpose. But, the measurement was not free from the errors. The issue with the device was that the measured value was much less than the actual due to improper sensing of distance. This could be because of the skid of the front wheel.

Behead (1989) and Prasad (1990) developed a device for the computation of slip. The device computed slip by the comparison between the actual and theoretical speed. Photo sensors were utilized for counting the wheel rotations for the speed measurement. A disc with 6 nos. holes at the interval of 600 was mechanically positioned to rotate by the axle of the tractor. On either side of the discs, light sources and detectors were installed to sense the revolutions. The calculation was done by a microprocessor with the data generated by the sensors. The system had the drawback due to accumulation of dust and mud on the passage of light which is very common in agricultural environments. This, in turn, resulted in to errors in the slip calculations. The errors also occurred due to skidding of front reference wheel.
Wang and Zoreb (1990) devised an information system for the drivers. Intel's 8052 MLC-I microcontroller was used for their measurement system. The schematic diagram is presented in the below Fig. 2.1 to explain the working of the driver information system. The system optimized the fuel efficiency, TE and overall cost of operations. Driver was provided guidance to adjust various controls to adjust right drive speed and throttle positions. Operation cost was minimized and the field capacity could be improved. However, the reliability of this system was not as per the customer expectations.

Salaeque and Jangiev (1990) developed a measurement system for 4WD farm tractors. The system monitored few operational parameters including slip. The data processing was done by a microcomputer. The parameters such as slip, speed and TE could be measured by this instrument. However, the system did not receive wide acceptance due to the complexity of operations.

Reed & Turner (1993) developed a method for the accurate measurement of slip values of a 2WD traction device with the help of radar sensor after reviewing the contemporary and previous computation techniques. The principle used by the radar sensor was Doppler effect. When a radio wave from a moving vehicle is focused towards a surface, the wave reflects with a change in frequency. The percentage difference between the two frequencies is directly proportional to the speed of the vehicle. In this case, the radio signal was focused by the radar gun towards the ground and difference of

Fig. 2.1: Tractor Driver's Information System (Wang and Zoerb, 1990)
the frequencies was considered for slip calculation. The device was compatible with any make and model of 2WD tractors. The measuring system exhibited good accuracy but the system was not widely adopted due to very high cost of the radar sensors. Also the system did not work well when the ground speed was less than 0.5 Kmph. However for laboratory use, the device worked satisfactorily. The radar gun used on a traction device is shown in Fig. 2.2 and Fig.2.3 below.

\[
\text{Velocity} = \frac{\lambda}{2 \cos \theta} \times F_r - F_r
\]

\[\ldots (2.4)\]

Fig 2.2: Radar Sensor (Reed and Turner, 1993)

Fig. 2.3 Use of Radar Sensor on a Tractive device (Reed and Turner, 1993)
A general purpose instrumentation system was designed by Mclaughlin et al 1993. The system was checked for its performance in a tractor for the evaluation of different parameters such as consumption of fuel, speed of engine, speed of wheels, ground velocity and the torque of the front and rear wheels. He used transducers for sensing various parameters. The output data from the transducers were amplified before feeding to the microprocessor based data logger which was controlled by flexible software. The device was designed to accommodate future up-gradation.

A microprocessor based measuring device was developed by Sinhala (2001). A steel wheel having spokes at 20° interval was fixed to rotate along with the axle of a 2 WD tractor. For sensing the rotation, a proximity sensor was placed close to the spoke of the wheel. When the wheel rotated, the spoke at the interval of 20° approached the proximity sensor. The magnetic pick up signal generated a voltage which was fed to the microprocessor unit. The microprocessor sensed and compared the data from front and rear wheels with no load and load conditions. The microprocessor was programmed accordingly to calculate the slip. The sensed slip was matched with the manual calculations to validate the performance.

Riemann and Johan (2007) designed a microcontroller based slip measuring system for 2WD tractor for the computation of slip during practical use. Sensor used for the instrument comprised of various components such as power supply; throttle position sensor, gear position sensor, the sensor for wheel RPM, data processing system, display system etc. Power supply for the device was catered from the starter battery of the tractor. Proximity switches and rotary potentiometer were equipped on the tractor for the indication of throttle position and wheel rotation. The performance was evaluated both on tarmacadam road and on actual field. There was a 5-10% variation between indicated and actual slip for both the surfaces which appears to be at good level of accuracy.

From the above literature survey, the three methodologies have been emerged as given below for the measurement of the actual ground speed of the tractor which is essential for slip measurement.
i. **Use of non-powered wheel:** In the case of non-powered vehicles, the method was quite simple where the speed depends on soil texture, weight transfer and skid of front tyre. In such cases, the error in slip measurement is not more than ± 2%.

ii. **Use of additional or fifth wheel:** Generally the 5th wheel was used in the case of 4WD vehicles. The measurement of speed is independent soil conditions, weight transfer and skidding of front wheel. However, the use of fifth wheel has difficulty in managing on undulating and rough terrains.

iii. **Doppler device:** It was possible to measure the actual speed accurately by using this device. The device has absolute reliability but very costly. However, the demerit of the device is its unsuitability for the speed below 0.5 km/h.

Because of the low cost, choice of front wheel as reference for actual speed measurement is widely considered.

### 2.2 Depth Measuring Methods

Various factors such as type and texture of soil and type of tractor-implements combinations with their characteristics affect the depth of implements. Draft of the tractor depends on various factors like soil texture, moisture, tillage depth, working width, hitch geometry with stability arrangement of implements and the forward velocity. Implements have higher draft in clay soils as compared to the loam and sandy soils.

Collins (1991) developed a measurement method while transporting rear mounted implements to forecast the load. This immensely helped the instrument designers for designing and estimating the loads for the futuristic machines. This method also helped the formulation of endurance test procedures.

To test the performance of a tractor and implement combination, Aggarwal (1993) designed a simulator. With the help of two bottom MB plough and 11 tyne cultivators, the theoretical study was conducted. Computer program was developed for the evaluation of the tractor performance with the attachment of implements.
Lee et al. (1996) developed an optical/ultrasonic transducer for computing the ground height. Both indoor and outdoor tests were performed to test the reliability of the device under different situations such as height of the transducer above the ground level, ambient temperature, intensity of the sunlight, texture of the soil and the ground configurations. Although the ground surface was un-even, the accurate measurement of distance was made by the optical sensing system. While, because of moisture, the optical device got affected by reflection of light, the ultrasonic device was stable due to its immunity to the light reflections. The wide beam width was a disadvantage for the ultrasonic sensor which particularly receives the reflected signals from an uneven surface of the soil.

Muniswar (1998) devised a system to perform vertical and horizontal simulation of the three point linkage in the tractors. The critical dimensions involving the linkages were thoroughly studied and the effect on the points of the link was identified by the simulation process.

Singh (1998) developed a system to simulate a program to forecast the mechanical advantage, maximum capacity for lifting and finding the optimum point of lower pivot position of the lift rod.

For the calculation of draft and depth of an implement system, a DAS was designed for a 3-point linkage implement by Al-Janobi (2000). A rotary position sensor was fixed to the rock shaft which measured the depth of angular position of the linkage implement. The system was capable of producing reliable results.

A new concept for the 3-point hitch was developed by Lang and Harms (2002). The developed system used hydraulic cylinders to arrange three point hitch mechanism with more flexibility. The functionality was extended by the concept of the modified 3-point hitch. Also, the constructional complexity was taken care. This was an important step as compared to the common trend for automatic operation and the management systems for tractor-implement combination.

Ambike and Schmiedeler (2007) experimented on kinematic design of 3-point hitches. They used geometric constraint programs by which design parameters were
manipulated. At the same time, the diagram was automatically updated to fulfill the imposed constraints.

Dikshit (2007) simulated the forces acting on 3-point linkage of a diesel tractive device by developing simulation program with the help of computer program in Visual Basic language. The stress exerted on these links was determined by software. Actual field data indicated the forces acting on the links. These links with optimized sections were arranged by making necessary fabrication with the standard procedures. Tests carried out in the laboratory for the lower links to quantify the actual exerted stress. Strain gauges were also positioned at five different positions of the lower link. The arrangements sensed the stress on the link. As per the actual farm situations, the links were loaded by hydraulic machinery.

2.3 Draft Measurement Methods

The three point linkage dynamometer is generally used for the measurement of draft in the tillage system. The draft control system automatically raises or lower the implements as per the intensity of resistance of the soil. The sensing device actuated the hydraulic systems to lower or raise the implement system. The sensing system was located on either lower or on the upper link depending on the size of the tractor. By using the manual control lever, the position of the draft could be adjusted. As per the load, the implement raise or lower its height to adjust the depth of the implements.

The draft control system developed by Harry Ferguson was first of its kind where the sensing device was located on the upper link and responded to a compressive force. As the draft increased, the compressive force would increase. It was observed from the experiments that the compressive force in the upper link became smaller as the size of integrally mounted plough was increased.

The three point linkages are classified into two main groups (Chaplin et.al.1987). In the 1st group, sensors were fixed between the tractors and implements. In the 2nd case, modifications were done on dynamometer arms for accommodating the sensors. The frames were modified in many ways to meet the requirements. (Scholtz, 1964; Johnson
and Voorhees, 1979; Carter, 1981; Chaplin et al, 1987; Barker et al., 1981). The free use of PTO shaft was permitted in some of the designs.

Nadre (1977) experimented on 3 points linkages in MB plough, disc plough and cultivators for measuring the forces. In his finding, it was observed that points of the hitch were dependent on the forces, angles and locations of the links in the vertical plane. The performance of the tractor differed because of variation of dimension of 3 point linkages and the position of link points. The bending force primarily affected the position of VHP.

Bandy et al. (1985) devised two methods for measuring the 3 point hitch forces. According to the first method, he measured the 3 dimensional forces in lower links. In the same way, as per the 2nd method, he used load sensing clevis pins. The dynamic weight transfer coefficient for other mounted implements were also explored by him.

Majumdar (1993) carried out experiments by mounting strain gauges on the neutral axis of lower links for the measurement of axial bending forces during measurement of forces in 3 point linkages of tractors attached with MB plough. For the measurement of the compressive forces, a strain gauge was installed on top link.

As observed from the related literature, the most of the data acquisition system worked in combination with data logger and microcomputer. This was required to record the output signals of the strain gauges. Information passed to the microprocessor controlled DAS through magnetic tapes. Tractors achieved greater versatility by mounting the data acquisition system. Al Janobi (2000) devised a data acquisition system for the measurement of the forces in 3 point link implement forces. He used the depth sensor for measuring depth of the mounted implements. An extended ring in octagonal shape was installed with the transducer. On the top link, a compression/tension load cell was equipped. The rock shaft was installed with a rotary position transducer for measuring the implement depth.

2.4 Influence of Slip on Tractive Performance

For maximizing the performance of the tractor, the matching of forward speed with a tractor implement system is essential. This improves the fuel efficiency. The
performance of a tractor is dependent on TE and the dynamic traction ratio. It is the measure of percentage of axle power transformed to the drawbar power.

Wismer and Luth et.al. 1973, Gee Clough et al. 1878 and Brixius et al. 1987 developed the empirical equations for predicting drawbar performance such as wheel slip as well as other soil parameters. It was found from all above factors that TE would be maximum when the slip of the drive wheels was maintained within the optimum ranges. Zoz (1970) reached at a conclusion that different kind of soil texture would have a different slip ranges where TE is maximum.

As per the observations of Thansandoe (1977), wheel slip was considered as a vital parameter for observing the performance of tractor in a particular farm conditions. Therefore, controlling tractor slip is very essential for conserving fuel, increasing field capacity, decreasing wear and tear of tyres and the improvement of overall efficiency.

Qaisrani et al. (1992) found that by implementing proper ballasting method, wheel slip, fuel consumption, and wear and tear of tyre were reduced up to a large extent. This was possible by proper ballasting method. Byerly et al. (1989) and Jenane et al. (1996) found that when a tractor operated near the highest TE, it resulted in significant saving of fuel when the slip was maintained between the ranges from 10% to 25%. Any value of slip beyond this range increased fuel consumption and brought down the overall tractive efficiency. However the range would differ with different type of soils.

Performance of tractors was evaluated by Tiwari (2006) in a controlled bin condition with the help of 4 no’s of tyres under the test (12.4-28, 13.6-28, 14.9-28 and 16.9-28). His experiment was intended to calculate the coefficient of traction, prediction of TE at changing test conditions with varying percentage of slip. Lateritic sandy clay loam soil was considered for carrying out the experiments. A test jig was prepared to mount the test tyres. A load was accordingly arranged for ensuring varying pulls at 3 dissimilar conditions. The experiments were done with the cone index ranging from 600/700 to 1700/1800 kPa. The deflection of tyres was varied from 18-26% by load variations and tyre inflation pressures. The coefficient of tractions and TE at different percentage of slip with varying conditions were calculated from the test observations. The plotting as
presented in Fig. 2.4 explains the TE and slip with coefficient of traction with different soil cone index. As per his conclusions, all observations had peak TE in the range of 60-70% was within 14-18% slip range.

![Fig. 2.4 Tractive Efficiency Verses Slip for Different Soil Conditions](image)

### 2.5 Existing Draft Control System

The draft control system is comprised of a tractor connected with implement system which has a hitch and lift mechanism. For the depth control system, the hitch is connected to one end of the implement while the other end is attached to a height adjustment system. There are two hydraulic cylinders, one for controlling lift whereas, the other manages the height. The fluid source and phasing valve and auxiliary service valves are always in communication selectively. The first hydraulic cylinder is actuated by the auxiliary service valve for raising the hitch while the phasing valve couple the second cylinder to the 1st cylinder to ensure full raising of both ends of implement by synchronous operation of both cylinder.

Cowell and Len (1967) experimented with the help of two tractors on a same sinusoidal field having the wave length of 30ft and 40ft amplitudes. The observation was made to find the depth control performance of draft controlled ploughs. It was found that there was a wide variation in the depth of operation. The errors increased in depth control when forward speed was increased. Also, there was very small effect of the response
control on the depth control operations. Cowell (1969) explained the shortcoming of DCS as compared to SCS and developed a device which was necessary for quantities forecasts of dynamic behavior of a DCS for determining the transfer function of an implement.

Dawyer et al. (1974) investigated and derived a control instrument which handled multiple parameters. Experiment was conducted for different situations of field conditions to study the effect of variation of different parameters. It was intended to find out how the draft increased with speed above 5 Kmph without improvement of control parameters. He explained the method to improve the control by decreasing dead band and increasing the lift rate. However, the improvement of the control mechanism has some limit as it affects the stability and poses discomfort to the drivers. Instability happens when the quantum of lift is just enough to permit the detected parameters to pass over the dead band during the delay period.

An experiment was conducted by Crolla and Pearsons (1975) by using random draft variations input which naturally occurred in the field surfaces. His investigations were based on the following grounds:-

(a) Type of implements

(b) Type of soil

(c) Forward speed.

It was revealed that

(1) Implement influenced the draft control performance and the forward speed rather than soil condition.

(2) Above 8 Kmph, a very rapid increase of draft variation was observed and there was need for improvement of control function if higher tillage speed was considered.

(3) Because of the limits on the stability factor, draft control performance can't be achieved up to a satisfactory level.
Crowell and Milne (1977) developed a hydro-mechanical implement control system by using pure draft sensing and modified linkage geometry. By summation of forces in the top and bottom mounting of the 3 point hitch, the sensing of draft force was provisioned. The conclusion was made in such a way that the used control systems had time delays stretching from 0.05 to 0.15 sec. This type of time delay would certainly affect the stability. So the simplest practical solution was to engage a controller with small time delay.

Singh et al (1991) analysed the repeat variation of the draft of a MB plough to access the response of the tractor DCS in a heavy clay soil. The implement control mode such as depth of operations and draft control methods were adopted for carrying out the experiments. Three different speeds i.e. 0.45, 0.65 and 0.90 m/s and two different depth of operation were chosen at 24 and 29 cm. The experiment was intended to conclude their influence on the cyclic variation of draft. It was noticed that the draft force was cyclic in nature with distinct trough and peak values. The soil rupture length was found to be 1+/−0.2 m. The response of draft control was influenced by the lower frequency range of the draft. The performance was better at low speed third gear than the two other lower speed gears.

Sanchez et al (2003) noticed variability of draft value during the field operations. Large number of variations was observed in the soil deforming forces. The FET analysis of tillage data indicated that the frequency components of the amplitude spectrum generated by FET depended on the condition of the soil. It may be concluded that the DCS of the present generation of tractor is unable to control the draft efficiently in the field operations.

2.6 Slip Control System

In order to enhance the utilization of engine power, Ismail et al. (1981) carried out an experiment by controlling the tractive efficiency through slip variations. It was discussed as to how the tractive efficiency can be improved by slip control mechanism. Adjustment of axle load and coefficient of traction or wheel slip was made to achieve the desired results. An analogue o/p of the slip was used to activate a 12V DC motor
whenever slip deviated from the desired range. Through a chain of gear mechanism, the motor could rotate the draft control shaft of the tractor hydraulics. Whenever the slip varied beyond the desired limit, the implement height was raised or lowered by the operators as per the requirement to bring slip within a definite range. It was observed from the field results that there was possibility to manage the slip within desired range. The field parameters such as slip, draft and both ‘slip & draft’ were compared by Ismall et al. (1983) to evaluate the field performance.

![Fig. 2.5 Draft, Slip and Combined Control System](image)

The DCS was compared with SCS on the same tractor by using force on the top link as a control process. As per the observation, it was noticed in Fig. 2.5 that the slip control established better controlling effect over the draft control process resulting higher efficiency. Pranav P.K. et al. (2010) developed a slip sensing and control system for 2WD tractor and compared the drawbar performance parameters such as tractive efficiency, fuel consumptions, field capacity, depth measurements with the existing DCS for different field conditions and the advantage of slip control to improve the performance. He established that the slip control methodology is the best method to control the performance of the tractive device with respect to draft control system. He used automatic control of depth through stepper motor arrangements to maintain the slip within a desired range. Hence, it was established that tractive efficiency could be improved by controlling the wheel slip during actual field operation.
2.7 Effect of Soil Salinity on Slip

Salinity of the soil has influence on the slip characteristics. Whenever the salinity of the soil increases, slip gets reduced making the slip inversely proportional. An excess of dissolved salts in the soil can be detected by electrical conductivity test by using electromagnetic sensors.

2.8 Effect of Soil Moisture on Slip

Soil moisture is a critical soil parameter and its accumulation happens due to numerous pores in the soil. Due to the existence of pores in the soil, it holds sufficient water to keep it moist. It is observed that soil moisture is directly proportional to the slip. As the water is good conductor of electricity, clay soil conducts better than sandy soil which has lesser number of pores in it. Soil moisture can be measured by electrical method. It is observed that soil moisture is directly proportional to the slip.

2.9 Traction Models

Tractor is important farm machinery is widely used for field operations. Scientists have paid great interest for the improvement of its performance. It is established from the study that the performance of tractor depends on soil conditions, machine configurations, traction elements and the type of implement attached for drawbar works (Brixius, 1987). For improving the performance of tractor, the measurement process of performance parameter is very essential. The performance parameters can be studied by the traction equations developed by the scientists during the course of their investigations. It is now possible to investigate many problems to improve the design, optimize parameters, deciding forward speed and also do a proper matching of implements with the tractor etc. Improvement pertaining to traction performance can be achieved by using computer models. The developed equations for coefficient of motion resistance and gross traction ratio have been presented as follows:-
MR
RWD = \frac{1.2}{Cn} + 0.04 \tag{2.6}

\frac{T_w}{R \times RWD} = 0.75(1 - e^{-0.3CnS}) \tag{2.7}

Where,

\begin{align*}
P &= \text{wheel pull} \\
RWD &= \text{rear wheel dynamic load;} \\
e &= \text{natural logarithms;} \\
T_w &= \text{wheel torque;} \\
R &= \text{wheel rolling radius;} \\
MR &= \text{motion resistance force (towed force) of wheel;} \text{ and} \\
S &= \text{wheel slip.}
\end{align*}

Brixius (1987) developed new equations as an improvement of similar research for the prediction of tractor performance tested by Wismer and Luth (1973). This widened the developed equations by Wismer and Luth (1973) which became very popular. Brixius models are similar to the experiment made by John Deere Co in USA on the drawbar of farm tractors. A curve fitting technique was adopted for the prediction of tractive performance of bias tyres operations in cohesive frictional soil. He predicted the parameters such as motion resistance, net traction and TE, considering them as the function of soil strength. The following equations are restricted to tyres with a b/d ratios ranging from 0.1 to 0.7. The static tyre deflections ranged from 10% to 30% of the undeflected tyre sections height and RWD/(bd) values range from 15 to 55 kN/m² (ASAE, 1997).

\begin{align*}
GTR &= \frac{T_w}{R \times RWD} = 0.88\left(1 - e^{-0.18t}ight)\times\left(1 - e^{-7.5s}\right) + 0.04 \tag{2.9}
\end{align*}
Where, 

\[ B_n = \text{mobility number} = \left( \frac{C_{ld} \cdot \text{RWD}}{\text{RWD}} \right) \times \left( \frac{1 + S \delta}{h_t} \right) \left( 1 + \frac{3b}{d} \right) \]  \hspace{1cm} \text{...(2.11)}

\[ \text{RWD} = \text{rear wheel dynamic weight, kN}; \]
\[ \text{CI} = \text{cone index for the soil, kPa} \]
\[ b = \text{unloaded tyre section width, m}; \]
\[ d = \text{unloaded overall tyre diameter, m}; \]
\[ h_t = \text{tyre section height, m}; \]
\[ \delta = \text{tyre deflection, m}; \]
\[ S = \text{slip, decimal}; \]
\[ \text{T}_w = \text{torque applied to wheel}; \]
\[ \text{MR} = \text{motion resistance}; \]

Evans et al (1991) developed a model involving ballast selection to forecast the traction. The experiment was based on the equation earlier derived by Brixius (1987). There was an improvement of traction prediction by modification of coefficient of the tractive equations. This improvement was for specific tractor driven on a grass surface. The slip parameters was varied from 7.5 to 4.15 and the slip percentage in the MR equation came down from .5 to 0 as shown below:-

\[ \text{GTR} = 0.88 \left( 1 - e^{-0.11S} \right) \times \left( 1 - e^{-4.15S} \right) + 0.04 \] \hspace{1cm} \text{...(2.12)}

\[ \text{MRR} = \frac{1.0}{B_n} + 0.04 \] \hspace{1cm} \text{...(2.13)}
Tiwari et al. (2009) developed the traction prediction eqns. from his experiments. He conducted experiment in controlled soil bin condition by using lateritic sandy clay loam soil.

For the development of building traction model, the data such as axle torque, wheel slip, drawbar pull, and rolling resistance, normal forces on the test wheel axle, tyre deflection and tyre dimensions of the four sizes of bias ply traction of tyres were collected.

\[
GTR = \frac{T_w}{r} \times RWD = 0.66 \left(1 - e^{-0.09B_s}\right) \times \left(1 - e^{-5.25s}\right) + 0.035 \tag{2.14}
\]

\[
MRR = \frac{MR}{RWD} = \frac{1.2}{B_n} + 0.035 + \frac{0.77 \times S}{\sqrt{B_n}} \tag{2.15}
\]

Al-Hamed et al (1994) prepared a spread sheet for the calculation of TE in the radial wheels. Followed by his experiments, many other researchers such as Zoz and Grisso (2003), Goering and Hansen (2004), experimented in the same line to predict the drawbar performance of tractors. Pranav and Pandey (2004 and 2008) developed user friendly SW for predicting drawbar performance and ballast controlling methods in agriculture tractors. The developed SW could calculate the performance of tractor including TE and Ballast requirement.

Kumar and Pandey (2009) also explained the prediction mechanism of drawbar performance of 2WD tractors for field processes for both bias and radial ply tyres.

Slip is affected by moisture and is directly proportional to the same. Slip can be predicted by measuring soil moisture. The soil moisture, keeping other parameters of soil constant, directly affects electrical conductivity.

Electrical conductivity of soil, therefore, is an indirect measure of slip of traction wheels. On literature survey no previous study could be available. Slip is affected by salinity of soil and is inversely proportional to the same. By measuring soil salinity, slip can be predicted. This process needs more study and investigations. Cation exchange capacity (CEC) is related to percent of clay and organic matter (O.M.). As the percent of
clay and organic matter increases, the CEC also increases. Research findings show the correlation between conductivity and CEC through its relationship to clay (William and Hoey, 1987). But literature survey did not provide reference of any previous study on relationship between moisture and slip.