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# Subsoiler Development Trend in the Alleviation of Soil Compaction for Sustainable Agricultural Production

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***ABSTRACT:****Soil compaction has been an issue and problem in the mechanisation of agriculture for sustainable production of food. The challenge to alleviate soil compaction is on-going and is likely to continue for some time to come because energy requirements for crop production continue to increase due to increase in population, thereby bringing heavier agricultural machinery to the field. However, soil compaction can be removed from our fields and its effect alleviated for sustainable crop production. This paper therefore reviews the trend of the development of subsoilers which is veritable equipment for removing hard pans from arable soils. Searchlight on Subsoilers features, design and development, power requirements, effectiveness and efficiency was carried out with a view to identifying efficient ones and/or propose parameters for better designs. Different works by researchers on types and shapes of subsoilers have been studied with respect to draft and energy requirements, soil disturbance, alleviation of compaction and ease of operation. Subsoiler shapes such as Swept shank, Straight shank, Curved (semi-parabolic) shank, Parabolic shank, Winged type and no-wing type, rotary, Vibration and non-vibration types, Coulter subsoiler, Coulter with blades subsoiler, Coulter with blades and reversing subsoiler were considered. An important consideration concerning subsoiling is the amount of soil disruption for different soil conditions to increase the long-term benefits of subsoiling. Subsoiling requires high draft and mechanical energy. Draft requirements depend on soil type and properties, manner of tool movement, and tool shape, travel speed, depth of operation, and the amount of soil compaction. In order to achieve better soil disturbance, reduced draft force and energy requirements, and as well as less traction resistance, site specific and in-row tillage practices for enhanced agricultural development,the application of vibratory (oscillatory) and rotary subsoilers in modern day design and development of subsoilers may be preferred for lower overall demand on engine power, to meet the challenges of today.*

***KEYWORDS:****Alleviation, Energy Requirements, Development Trend, Drought, Subsoiler, Soil Compaction.*

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## I. INTRODUCTION

Development and evaluation of tillage tools performance, and their energy requirements during operation has been of great concern to the engineers and farmers as this has very important effect on the efficiency of tillage operations. Tillage tools are mechanical devices used for applying forces to the soil to cause one or more of cutting, movement, fracturing, loosening, overturning and pulverization of the soil to prepare a seed bed. Friction between soil bodies, cohesion between the soil particles and friction between soil and tool are the most important elements in the mechanical study of the tilled soil body. These are the major effects that the external force has to overcome to break the soil into smaller aggregates (Ademosun, 1990). Some studies have been useful in calculating the force that the tool will have to apply to the soil to cut and to determine the shape and volume of soil cut. These models have shown the relation between the tool geometry, force requirements and the total cut soil volume. Studies have also shown that energy requirements increase with tool width at a fixed depth, and specific energy efficiency for cutting alone increases with tool width (Manuwa and Ademosun, 2007).

Subsoiler is a tractor mounted implement used to loosen and break up soil at depths below the level of a traditional disk plough, mouldboard plough, chisel plough or rotary plough. Most tractor mounted cultivation tools will break up and turn over surface soil to a depth of 15-20 cm, while a subsoiler will break up and loosen soil to twice those depths. Typically a subsoiler mounted to a Compact Utility Tractor will reach depths of about 30 cm and above. The subsoiler is a tillage tool which will improve growth in all crops where soil compaction is a problem. The design provides deep tillage, loosening soil deeper than a tiller or plough. Agricultural subsoilers, according to the Unverferth Company, can disrupt hardpan ground down to 60 cm depth (Mollazade*et al.*, 2010, Li *et al.*, 2012).

Tillage is the physical manipulation of soil by mechanical forces (using tillage equipment) to change its structure, strength or position by cutting, shattering, loosening, inverting (turning) and mixing the soil to prepare an optimum condition for crop production (Gill and Vanden Berg, 1968, Mckeys, 1985;Mollazade*et al.*, 2010). Thepurpose of tillage tool design is to create a mechanical system, a tillage machine or a series of machines capable of controlling theapplied forces in order to achieve a desired soil condition. Tillage tool can be considered a single soilworkingelement whereas tillage implement will include a group of soil-working elements. A tillage implementor machine will include the frame, wheels, or other structural unitsthat are needed for guidance and support.

Today, there are many implements which are used for primary and secondary tillage operations. But,traffic of heavy agricultural machinery or the actionof tillage tools, particularly where the same tool isused at the same cultivating depth in successiveoperations, lead to soil compaction (Srivastava *et al.*,2006, Osman *et al.*, 2013). According to Guerif (1994), the hard paninduced by mouldboard ploughing, combinessmearing in wet conditions and compaction by thefurrow wheel of the tractor. Hard pans restrictvertical growth of roots, which reduces extraction ofwater and nutrients from deeper strata. Crop yield isreduced in situations of moisture shortage. Hardpansalso accelerate soil erosion by decreasing infiltrationand increasing runoff and soil loss.

Subsoiling usually is done to break upimpervious soil layers below the normal tillage depthto improve water infiltration, drainage and rootpenetration. Some outstanding results have beenachieved from subsoiling. Yield increase of 50 to 400percent has been reported from subsoiling under theright soil and moisture conditions and in the rightareas (Borghei*et al.*, 2008). To alleviate the problems of soil compaction, subsoiling is carried out. Subsoiling or deep tillage is a field operation usually performed using a subsoiler to break up compacted layers of soil at depths of 25 - 60 cm deep and 60 - 150 cm space channels without inversion, using knife-like shanks that are pulled through the soil to create continuous grooves. The subsoiler is similar in principle to thechisel, but it is more heavily built and rigid foroperation at depths of up to 90 cm to loosen deep soillayers for the promotion of water movement through the tillage pan, and to enhance soil conservation, soil moisture storage, rootgrowth, and crop yields (Raper*et al.*, 1998; Abu-Hamdeh, 2003; Williams *et al.*, 2006). A tractor of 40 to 60 kW power is needed topull one subsoiler shank at a depth of 45 cm in heavysoil, while a large track-laying tractor in the order of50tons mass is needed for three-winged subsoilersoperating at 90 cm depth.

Subsoilers work best infirm soil where a hard layer prevents adequate rootand moisture penetration. If soil is uniformly texturedto the depth of subsoiling, or is too wet, subsoiling isusually not as productive. Slope of subsoiler shanksand points affects draft and soil shattering. Whenshanks are inclined forward, they lift and break thesoil much better than if they are vertical, or nearly so.Curved shanks work under hardpan, lifting andshattering the soil ahead of and between shanks.Subsoilers work in the very arduousconditions, so they bear heavy dynamic loads.Therefore, proper design of these machines isnecessary in order to increase their working life time and reduce the farming costs (Mielke*et al.*, 1994, Jones *et al.*, 1996;Mollazade*et al.*, 2010).

Draft reduction is one of the most important performance indicators of subsoilers. Hence several researchers have studied various parameters to minimize draft force and total power (Yow and Smith, 1976,Sakai *et al.*, 1988).

The objectives of this work therefore are to:

i. identify various types of subsoiler developments and usage
ii. discuss the efficiencies of the subsoilers in terms of draft and energy requirements, soil disturbance, alleviation of compaction and ease of operation, and
iii. recommend types of subsoiler development to meet the challenges of today.

## II. SUBSOILER DEVELOPMENTS AND USAGE IN RECENT YEARS

### 2.1 Subsoiler Shapes and Designs and their Effects in Soil Disturbance

Research on the shape of subsoiler shanks was conducted at the National Tillage Machinery Laboratory in the 1950's (Nichols and Reaves, 1958). They found draft requirements with curved shaped shanks to be 7 to 20 percent less than with straight shanks. Although this research indicated a reduction in draft requirement for a subsoiler with a curved shank, the predominant subsoiler design of the 1950's and 1960's had either a straight shank or a shank inclined about 10 degrees. Tupper (1974) defined a specific curved subsoiler design as a parabolic curve and in summarizing two years of research, he reported a yield increase due to subsoiling (Tupper, 1977). In comparing the parabolic subsoiler to a conventional subsoiler, he reported a reduction in power requirement and a 43.4% reduction in wheel slip. Payne and Tanner, (1959) reiterated that draft was relatively insensitive to approach angles between $20^0$ and $50^0$ but increased very rapidly as the approach angle exceeded $50^0$. Additional work further defined draft requirements and vertical forces on tillage tools with approach angles from 20 to $132^o$ (Tanner, 1960).

Odey and Manuwa (2016) presented a step-by-step approach towards design of narrow tillage tools. Determination of tool width (w), angle between the tine face and the soil failure plane at working depth (ϴ), rake angle **(**αc**)**, inclination factor (K), tine category, area of soil disruption, void (v) created by tine, tool forces and power requirement; and other major soil and tool parameters should be identified and defined for researchersto follow and improve on in development of subsoilers for effective agricultural production. More attention should be given to design process that tends towards reduction in the magnitude of specific draught for overall benefits of tillage process.

There exist different shapes of shank designs in subsoiler. Shank design affects subsoiler performance, shank strength, surface and residue disturbance, effectiveness in fracturing soil, and the horsepower required to pull the subsoiler (Sakai*et al.*, 1993;Kees, 2008). Such shapes are Swept shank, Straight shank, Curved (semi-parabolic) shank, Parabolic shank, Winged type and no-wing type, rotary, Vibration and non-vibration types, Coulter subsoiler, Coulter with blades subsoiler, Coulter with blades and reversing subsoiler. Thus, subsoilers are designed with various shapes depending on the form of subsoiling operation that will be performed. An important consideration concerning subsoiling is the amount of soil disruption for different soil conditions to increase the long-term benefits of subsoiling(Raper and Sharma, 2004).Celik and Raper (2012) reported that many subsoilers have been designed and tested, using a number of subsoiling techniques for alleviating compacted layers of various types and conditions of soils.

Godwin (2007) revealed that aspect ratio (depth/width) and rake angle (α) are two major variables in the design and selection of the appropriate geometry for given tillage implements such as subsoiler. Wide blades and narrow tines with depth/width ratios less than 5 and rake angles less than 900 tend to fail the soil in crescent manner, with the wide blade creating a wide slot and narrow blade, narrow slot especially when the aspect ratio increases. As the depth/width ratio increases the soil failure changes such that there is a small crescent close to the soil surface but the soil at depth is forced laterally to produce a slot. Godwin (2007) further stated that implements designed with rake angles less than 900 (α<900) tend to cut, loosen, invert and smoothen the soil while implements with rake angles equal to or greater than 900 (α = > 900) tend to consolidate, disintegrate and compact the soil during operation. He concluded Minimising the draught force is not the main issue because reducing the magnitude of the specific resistance (draught force/disturbance) is much more significant as it is a better indicator of overall tillage efficiency.

There exists different shapes of shank designs in subsoiler. Shank design affects subsoiler performance, shank strength, surface and residue disturbance, effectiveness in fracturing soil, and the horsepower required to pull the subsoiler (Sakai *et al.*, 1993; Kees, 2008). Such shapes are Swept shank, Straight shank, angled or curved (semi-parabolic) shank, Parabolic shank, Winged type, rotary or oscillating, Vibration and non-vibration types, Coulter subsoiler, Coulter with blades subsoiler, Coulter with blades and reversing subsoiler. Thus, subsoilers are designed with various shapes depending on the form of subsoiling operation that will be performed. An important consideration concerning subsoiling is the amount of soil disruption for different soil conditions to increase the long-term benefits of subsoiling (Raper and Sharma, 2004). Celik and Raper (2012) reported that many subsoilers have been designed and tested, using a number of subsoiling techniques for alleviating compacted layers of various types and conditions of soils.

### 2.1.1 Straight Shank and Bentleg(Swept) Shank Subsoilers

Upadhyaya*et al.* (1984) found that a straight shank subsoiler mounted at a positive rake angle gave reduced draft compared to curved subsoiler in sandy loam soils. Kumar and Thakur (2005) reported that single leg conventional subsoilers with curved and straight leg have beenintroduced in India to alleviate soil compactionproblems in the lower soil profile, but require high draft. To overcome these problemsa winged type subsoiler with and withoutleading tines have been designed and introduced.To compare the performance of different subsoilers namely, conventional curvedleg, conventional straight leg, winged and winged with leading tines on the basis of draft, soil disturbance and specific draftatworking depths of 250, 300, 350 and 400 mm, an experiment was carried out by Kumar and Thakur (2005). Four different types of subsoilers were used in the study viz (1) Conventional straight leg, (2) Conventional curved leg, (3) Winged, and (4) winged subsoiler with leading tines. Results have shown that the critical depth of conventionalcurved leg subsoiler was 350 mm. However,the critical depth for other subsoilerswas not observed even upto 400 mmdepth. At350 mm working depth the draft force for winged subsoiler with leading tines increased by 39.75 % and 31.81 % over conventional curved and straight leg subsoilers respectively, while the soil disturbance increased by 3.03 times and 2.35 times, but the specific draft reduced by 53.90% and 44.00%, respectively.Swept shank subsoilers on the other hand are used mainly in forestry site for ripping through stumps and logging debris with the big magnum subsoil plough.

Raper (2007) Reported that a tractor-mounted three-dimensional dynamometer was used to measure draft, vertical,and side forces in a Coastal Plain soil in Alabama. Three subsoiler systems were evaluated at different depths of operation:(i) Paratill"bentleg shanks", (ii) Terramax "bentleg shanks", and (iii) KMC "straight shanks". A portable tillage profiler was used to measure both above and belowground soil disruptions. Shallower subsoiling resulted in reduced subsoiling forcesand reduced surface soil disturbance. The bentlegsubsoilers provided maximum soil disruption and minimal surfacedisturbance and allowed surface residue to remain mostly undisturbed. Bentleg shanks provide optimum soil conditions forconservation systems by disrupting compacted soil profiles while leaving crop residues on the soil surface to intercept rainfalland prevent soil erosion.

Kasisira and du Plessis (2009) worked on 'width prediction of a side circular crescent failed by a tillage tool in a sandy clay loam soil'. They conducted tests under field conditions with varying soil water content at the experimental farm of the University of Pretoria. Two Straight subsoilers in a tandem configuration were mounted onto an instrumented tillage dynamometer equipped with load cells that measured soil forces and exerted draft as reported by du Plessis and Kasisira (2003). From their findings, a model (equation 1) was proposed. The developed model adequately predicted the maximum width of the failed side circular crescent resulting in satisfactory prediction of the tilled soil volume. According to them this would lead to limit equilibrium analysis based models to sufficiently predict draft requirements of tillage tools. They concluded that models which are a function of soil water content predict better the size of the failed soil wedge than those that are a function of geometric parameters of the tillage tool, such as the model (equation 2) developed by Swick and Perumpral (1988).

$$S = 114.6e^{0.1413s} \quad (1)$$

$$S = 0.46(R) + 0.904(\alpha) - 6.03 \quad (2)$$

where,

S = maximum width of the side circular crescent

R = rupture radius

α = rake angle

### 2.1.2 Angled or curved shank Subsoilers

Thus, the subsoiler shape, the tillage depth, and soil moisture have important effects on the required draft and soil disruption. A consideration that exists concerning the shape of asubsoiler is how the draft will vary depending upon the depthof operation. Gill and Vanden Berg (1968) stated that:"Improper operation can defeat the advantage of decreaseddraft with a curved subsoiler. Unless the curved tool isoperated at its intended depth, all advantages of the curvemay be lost. Presumably, the curved subsoiler gains itsadvantage from the direction in which it applies forces to thesoil and the direction in which these forces cause the soil tomove. The advantage of the proper use of the design is lostif operation is too deep; the curved subsoiler operates asthough it were straight."

Comparisons between an angled and a curved shank in twosoil bins by Raper (2005),showed that shank positioned at a $52^0$ angle from the horizontal plane in the direction of travel had a lower draft requirement compared to a curved shank. Thus reduced draft requirements were found for the angled shank in a sandy loam soil with a trend towardreduced draft for the angled shank in the clay loam soil. Similar amounts of soil disruption were found for both shanks witha trend indicating greater disruption for the curved shank. He further stated that producers who conduct subsoiling at varying depths throughouttheir field may want to minimize draft force by using an angled shank, but should recognize that their soil may not be maximallydisrupted throughout the soil profile.

### 2.1.3 Parabolic Subsoilers

Tupper (1995) reported that a low-till parabolic subsoiler was designed at the MAFES Delta Branch in the spring of 1993 (Tupper, 1994). The shank had a parabolic curve, with a long gradual increase in slope from an approach angle of $22.5^o$ at the foot to $55^o$ approach angle at the soil surface when running at the normal operating depth of 16 inches. The shanks were cut with an electric eye torch from 1%-inchT-1 steel plate with 321 Brinnel Hardness Number (BHN). Shanks were designed to provide a 17 inch ground clearance at operating depth or a total height of 33 inches. The low-till parabolic subsoiler was designed with theshanks positioned at a $28^0$ angle from a vertical plane in thedirection of travel.Smith and Williford (1988) worked on conventional, parabolic, and triplex subsoilers. These subsoilers were operated on a uniform test site to evaluate theeffect of ground speed and subsoiler shape on powerrequirement. The triplex subsoilerrequired the highest draft and the parabolic required theleast. Draft for the triplex was approximately 2% greaterthan that for the conventional subsoiler except for thehighest speed which required 10% more draft. Theparabolic subsoiler draft ranged from 11 to 16% lessthan that for the conventional subsoiler over the speedrange tested. Powerrequired for the triplexsubsoiler was slightly higher thanthat for the conventional subsoiler. The largest verticalforce (downward) and smallest wheel slip values wereobserved for the parabolic subsoiler.

Mollazade*et al.* (2010) presented fatigue analysis of three subsoilers shapes, namely C-shape (parabolic), sloping shape (straight leg, but slanted), and L-shape (straight leg, without slant) in order to choose best one of them with maximum working life. After modelling of subsoilers, initialconditions and forces were exerted on the models. Clay loam soil condition was used as a tool to find the value ofsoil resistance forces.

Finally, models were analyzed with ANSYS software. Results showed that C-shape subsoilerhas biggest value of safety factor (about 5.27) in the fatigue analysis. Results of this research can help the designersof tillage tools to make similar works in their designs and reduce maintenance costs of subsoilers.

**2.1.4 Winged Subsoilers**

Moallazade*et al.* (2010) reported that a large track-laying tractor in the order of 50t mass was needed for three winged subsoilers operating at 90 cm depth. Kumar and Thakur (2005) revealed that the draft requirements of conventional subsoilers (straight leg and curved leg subsoilers) was significantly lower than the winged, and winged with leading tines subsoilers when they were compared. Moreover, the area of soil disturbance with winged subsoiler with leading tines was highest at all the depths of operation.

**2.1.5Vibratory or Oscillating Subsoilers**

Transmitting power directly totillage tools by oscillating them, appearsto provide an opportunity for reducingdrawbar pull. As reported by Choa and Chancellor (1973), Gunn andTramontini (1955) investigated the feasibilityof applying oscillation to an agriculturaltool. They, as did other investigatorsworking with positively driven oscillatingimplements, found that oscillatingthe implement or its working partsled to draft reduction. The use of vibrating or oscillating subsoiler is one technique that can be applied to reduce the draft force when the maximum velocity of oscillation is greater than the velocity of the tool carrier. Draft force reduction is the main advantage of vibratory tillage (Sakai, 2009). Sakai *et al.* (1993) reported that to achieve effective subsoiling with a medium size tractor (30-45 kW), a four-shank vibrating subsoiler was developed. This was evaluated in terms of draft reduction, power requirements, and riding comfort. More than 60% of draft reduction was obtained. For a certain vibrating condition, the power increment was only 2% of non vibrating power requirement. Tractor seat vibrations were minimized to acceptable levels by balancing oscillating soil cutting forces and moments.

Bandalen and Salokhe (1999) studied vibrating subsoilers and found that draft ratio decreased rapidly when the velocity ratio increased to 2.25. Thus, the draft ratio decreased slowly, when the velocity ratio was greater than 2.25. Slattery and Desbiolles (2002)reported that the lower draft requirement typically measured under oscillatory tillage reduces the reliance on less efficient drawbar power, such that a lower overall demand on engine power may occur.Shahgoli*et al.* (2010) studied vibratory ripper, vibratory frequency to the traction resistance effects, and found the non-linier relation between friction and traction resistance. On the other hand, Reeder *et al.* (1993) studied the effects of deep tillage on soil physical properties in silty clay loam and on crop yields. They found that two passes of a tractor recompacted the soil by the time the first crop was planted. They advised that control traffic is essential to obtain long-term benefits from subsoiling; because deep tillage increased soybean and corn yields (3-6.9 % in 1991 and 1.5-3 % in 1992) in areas not trafficked.

Li *et al.* (2012) carried out a series of tests to find out the optimum energy consumption and resistance of subsoilers. Two types of deep ripper shank (vibratory and non-vibratory shank) were compared to find out their influence on draft requirements, and soil physical parameters such as, bulk density and soil moisture content through the 400 mm soil layers from the surface of a silt-loamy soil. According to the researchers, a pull sensor and two tractors were used to measure the forces and soil pressure on the blade. It was revealed that the traction resistance with the vibratory subsoiler was 6.9 % - 17 % less than that of non-vibratory one.

Osman *et al.* (2013)revealed a reduction in traction resistance and bulk density for oscillating subsoiler compared to non-oscillating subsoiler by 16.49% and 6.4% respectively, when both subsoilers were studied to find out their influence on draft requirements, and soil physical parameters such as bulk density and soil moisture content.

**2.1.6Rotary Subsoilers**

Kooistra and Boersma (1993) measured the effects ofloosening practices on subsoil compaction in Dutch marinesandy loams. With deep rotary tillage or blade-typesubsoiling to depths of 600 mm the soil recompactedwithin three years to the same or worse physical properties.A narrow plough-mounted subsoiler blade extending about 100 mm below the plough bottom provided loosened zonestoo small to be recompacted in a few years by wide tractortires. Over the three-year period vertical root channelsformed and maintained the minimal improvement in soilphysical properties.Miszczak (2005) reiterated that the usage of rotary subsoilers can be partially justified by the higher efficiency of power being transferred to the soil rather than through the tractor wheels when shanks are pulled through the soil. In his study, Miszczak(2005) revealed that the coulter tines of rotary subsoilers exerted pressure on soil, causing soil disturbance and loosening, similar to passive narrow tines. Williams *et al.* (2006) used a rotary subsoiler to improve infiltration in a frozen soil for newly planted winter wheat. It was found that water storage in winter was significantly increased, and runoff and erosion were decreased as compared with the conventional subsoilers.

Celik and Raper (2012) recorded that rotary subsoiling is a new concept, not widespread in common hardpan loosening practices and had rarely been studied or used in commercial agriculture. Celik and Raper (2012) in their study, designed and evaluated ground-driven rotary subsoilers, with the objective of minimising soil disturbance and energy requirements while adequately disrupting compacted soil profiles. Thus, it was revealed that the coulter-5-blade normal direction and coulter-5-blade reverse direction subsoilers required considerably less draft power (from 10 to 68 %) when operated at depths of 25 and 38 cm, than when subsoilers of coulter-no-blade, and shank type were tested in both operation depths. Further results of their study showed that rotary subsoilers, that is, the coulter-5-blade normal direction and coulter-5-blade reverse direction type minimized soil disturbance and required higher draft energy (from 22.5 to 33.5 % ) per volume of disturbed soil than the shank-type subsoiler. Moreover the soil disruption paths of coulter-5-blade subsoilers have an advantage for row crops due to limited above-ground disturbance if seeds can be placed in the middle of the disrupted zone.

**2.2Power requirements of subsoiler**

Jones *et al.* (1996) asserted that several types of subsoilers have been manufactured which adequately shatter the soil to break up compaction. Subsoiler shanks may be parabolic (curved) shaped or straight and with or without wings. In general the power required to pull a parabolic shank is less than a straight shank. The addition of wings to either parabolic or straight shanks increases the power requirement. Subsoiling requires very high draft and mechanical energy. Draft requirements depend on soil type and condition, manner of tool movement, and tool shape. Therefore, for a given soil type and condition, draft requirements depend on geometry of the subsoiler shank, travel speed, and depth of operation.

**2.3Measurement and Prediction of Draft Forces**

Draft reduction is one of the most important performance indicators of subsoilers. Hence several researchers have studied various parameters to minimize draft force and total power (Yow and Smith, 1976;Sakai *et al.*, 1988).Draft, F is the total force parallel to the direction of travel that is required to pull the implement. Draft force required to pull tillage tools is primarily a function of the width of the implement and the speed at which it is pulled. For tillage tools operated at deeper depths, draft also depends upon soil texture, depth, and geometry of the tool.

Different theoretical models and calculations are available for calculating soil-cutting force. The universal earth equation of the two-dimensional analysis after Hiettiaratchi*et al.* (1966) as reported (Stadfford, 1979; Manuwa, 2009; Mollazade*et al.*, 2010; Mandale and Thakur, 2010; Mak*et al.*, 2012) have been used to estimatedraft or pulling force, F:

$$F = w(\gamma Z^2 N_\gamma + czN_c + c_a zN_a + qzN_q) \sin(\alpha + \delta) \quad (3)$$

Where:

$F$ = Draft force (kN),
$w$ = width of tool (m),
$z$ = the depth of tools (m),
$\gamma$ = the bulk weight ($kN/m^3$),
$N_\gamma$, $N_c$, $N_a$, and $N_q$ are dimensionless numbers,
$c$ = the cohesion (kPa),
$c_a$ = the soil-interface adhesion,
$q$ = the surcharge,
$\alpha$ = tine rake angle, and
$\delta$ = angle of soil-interface friction.

Nichols and Reaves (1958) measured the draft of a series of subsoilerswith macroshapes that ranged from the normal straight configurationto a deeply curved configuration. Draft wasmeasured in several soil conditions, and the results indicated thatthe subsoiler with the most curve required the least draft (Table 1).In a highly compacted and cohesive soil the curved tool requiredfrom 7 to 20 percent less draft than did the straight tool. Thisdecrease is substantial, and crude observations indicated that theresultant soil breakup was approximately the same for all toolshapes. The curved subsoiler presented an operational difficulty,however, since its greater length made turning and guiding the toolwhile it was in the ground difficult. No effort was made to describethe shape or to relate shape to draft except in the qualitative manner indicated in Table 1.Improper operation can defeat the advantage of decreased draftwith a curved subsoiler. Unless the curved tool is operated at itsintended depth, all advantages of the curve may be lost. Presumably,the curved subsoiler gains its advantage from the direction inwhich it applies forces to the soil and the direction in which theseforces cause the soil to move. The advantage of theproper use of the design is lost if operation is too deep;the curved subsoiler operates as though it were straight.

Table 1.Effect of shape on the draft of subsoilers operating ata depth of 12 inches and a speed of 2.5 kilometre per hour in varioussoils.

| Soil type | Draft force | Reduction in |
| --- | --- | --- |

| | Straight subsoiler (kN) | Curved subsoiler (kN) | draft due to curved shape (%) |
|---|---|---|---|
| Hiwasse sandy loam | 3.96 | 3.96 | 0 |
| Davison clay | 4.14 | 3.83 | 7.5 |
| Decaturrsilty clay loam | 8.12 | 6.29 | 22.4 |
| Sharkysilty clay | 8.90 | 8.10 | 9.0 |
| Hurricane clay | 9.43 | 8.10 | 14.2 |
| Houston clay | 9.07 | 7.38 | 18.5 |

Source: Nicholas and Reaves (1958)

## III. SUBSOILER DEVELOPMENTS AND CHALLENGES OF TODAY

Pillai and McGarry (1999) stated that compaction is regarded as the most serious environmental problem caused by conventional agriculture; it is the most difficult type of degradation to locate and rationalize, principally as it may show no evident marks on the soil surface. Ahmad *et al.* (2007) revealed that soil compaction is the main form of land degradation, affecting more than 11% land area. Chen and Weil (2011) added that soil compaction is a worldwide problem in modern agriculture associated with overuse of heavy machineries and intensification of cropping systems.Soane and Ouwerkerk (1994) and Hamza and Anderson (2005) revealed that compaction of agricultural soils is a global concern since it has adverse effects on the environment and consequently, agricultural production. According to them, it is estimated to be responsible for the degradation of an area of 33 million ha in Europe and is one of the major problems facing modern agriculture in the world today. According to Manor and Clark (2001), Petersen *et al.* (2004), Wells *et al.* (2005), and Alameda and Villar (2009), soil compaction reduces crop growth and yields, by restricting root development as well as water and air movement in the soil. Soil compaction in the surface layer can increase runoff and soil erosion, thus increasing soil and water losses.

According to Mari and Changying (2007, 2008) heavier and more powerful tractors and machines have been used on farms throughout the world. The aim is to reduce the human drudgery and labour; and corresponding increase in farm size and individual operator productivity. This has resulted in increased load on the soil causing compaction. In other words compaction is caused by working or driving on wet fields (wheel traffic), animal traffic or poor grazing management or natural process or raindrop impact (DeJong-Hughes *et al.*, 2001, Donkor*et al.*, 2002; Rocky, 2011).Alakukku*et al.* (2003) asserted that many human activities such as land clearing and development, and tillage normally carried out before planting, weeding and harvesting operations have been identified as major cause of soil compaction. From the aforementioned therefore, concerted effort must be geared towards developments and application of subsoilers to alleviate the problems of soil compaction. Selection of subsoilers for application therefore depends on the type and extent of compaction, soil type and properties, draft and energy requirements. Thus, for best performance of subsoilers, the following are suggested for application in achieving specific functions:

### 3.1 Deeper Operation

Upadhyaya*et al.* (1984) found that a straight shank subsoiler mounted at a positive rake angle gave reduced draft compared to curved subsoiler in sandy loam soils. Kumar and Thakur (2005) Reported that single leg conventional subsoilers with curved and straight leg have beenintroducedto alleviate soil compactionproblems in the lower soil profile, but require high draft.

### 3.2 In-row subsoiling

Aboveground soil disruption prior to planting is avoided in conservation tillage systems due to the need to keep plant residue in place. However, belowground disruption is necessary in coastal plain soils to ameliorate soil compaction problems. For use in conservation tillage systems, belowground soil disruption should be maximized while aboveground disruption should be minimized. To choose the best shank for strip-tillage systems which accomplish both objectives, the bentlegsubsoilers which provided maximum soil disruption and minimal surface disturbance and allowed surface residue to remain mostly undisturbed, is the subsoiler of choice. Thus, bentleg shank subsoilers provide optimum soil conditions for conservation systems by disrupting compacted soil profiles while leaving crop residues on the soil surface to intercept rainfall and prevent soil erosion (Raper, 2007).

#### 3.2.1 Site Specific Subsoiling

Odey and Manuwa (2016) revealed that a high-energy input is required to disrupt hardpan layer to promote improved root development and increased draught tolerance. Hence significant savings in tillage energy could be achieved by site-specific management of soil compaction. Site-specific variable-depth tillage system can be defined as any tillage system which modifies the physical properties of soil only where the tillage is needed for crop growth objectives.

**3.4Reduced Draft and Energy Requirements, and more soil disturbance**

The application of parabolic subsoiler is preferred when reduced draft and energy are required compared to the straight shank and bentleg shank (Smith and Williford, 1988). Incomparing the parabolic subsoiler to a conventionalsubsoiler, (Tupper, 1977) reported a reduction in power requirementand a 43.4% reduction in wheel slip.Thus, addition of Wing to subsoiler shanks enhances wider width of cut and greater soil disturbance (Kumar and Thakur, 2005).In order to achieve better soil disturbance, reduced draft force and energy requirements, and less traction resistance, the application of vibratory (oscillatory) and rotary subsoilers are preferred. Slattery and Desbiolles (2002) added that the lower draft requirement typically measured under oscillatory tillage reduces the reliance on less efficient drawbar power, such that a lower overall demand on engine power may occur. Li *et al.* (2012) revealed that the traction resistance with the vibratory subsoiler was 6.9 % - 17 % less than that of non-vibratory one. Hence, modern subsoiler design and development should consider the incorporation of vibratory and rotary mechanism in their subsequent study to meet the challenges of modern agriculture world over.

## IV. CONCLUSION

Soil compaction and its accompanying problems are inevitable as long as the quest for more food production continue to increase. Man shall continue to carry out design and development of different types of subsoilers to meet modern challenges. Consideration should be given to the design of shanks shape ofsubsoiler, as they are very important to the efficiency and effectiveness of subsoiling. Shanks should be designed to handle rocks, large roots, and highly compacted soils. Thinner shanks are suited for agricultural use. Thicker shanks hold up better in rocky conditions, but require larger, more powerful equipment to pull them and disturb the surface more. Bent offset shanks, such as those found on Paratillsubsoilers, have a sideways bend.

Subsoiler shanks may be parabolic (curved) shaped or straight and with or without wings. In general the power required to pull a parabolic shank is less than a straight shank. The addition of wings to either parabolic or straight shanks increases the power requirement. Subsoiling requires very high draft and mechanical energy. Draft requirements depend on soil type and condition, manner of tool movement, and tool shape. Therefore, for a given soil type and condition, draft requirements depend on geometry of the subsoiler shank, travel speed, and depth of operation. Thus, variation in power requirements depends on subsoiling depth, soil water conditions and the amount of compaction.In order to achieve better soil disturbance, reduced draft force and energy requirements, and less traction resistance, the application of vibratory (oscillatory) and rotary subsoilers in modern day design and development of subsoilers are preferred for lower overall demand on engine power.

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