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ENERGY AND AGROTECHNICAL INDICATORS IN THE TESTING OF MACHINE-TRACTOR UNITS WITH SUBSOILER

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ABSTRACT

The present-day agriculture involves anthropogenic effects on the soil, including the compaction and overcompaction of soil horizons at depths up to 1.2 m. The plowing of the soil with moldboard plows to a depth of 0.3 m results in the formation of a plow pan (hardpan), which hampers the development of plant roots; the optimum soil density for most agricultural crops is ρ = 1.1-1.3 t/m^3. There are supporters and opponents of deep subsoil plowing; only the plow horizon is the main object of studies. Chisel tools (subsoilers) have been studied on modernized models, which ensure the deep non-moldboard loosening to a depth of 0.30-0.45 m and more (down to 0.8 m) with the use of straight or slant shanks. Shank cultivators developed by the Siberian Research Institute of Mechanization and Electrification of Agriculture (SibIME), which penetrate to 0.30 m, were first used to control deflation. The American slant-shank subsoiler (Trade name, ‘Paraplow’) is the prototype of chisel implements. A range of tillage tools has been developed to form a ridged furrow bottom due to soil breakdown. Modernized tillage tools include breasts mounted on shanks for turning the upper (loosened) soil layer up to 0.20 m thick, as well as blades for cutting weeds, ridges, etc. Chisel modifications are mainly aimed at expanding their functional capabilities and decreasing the energy intensity of soil cultivation. The tests have confirmed the decrease of C, N, and humus losses; the improvement of the water and air conditions in the soil; the prevention of erosion; the improvement of tillage quality parameters; the increase of tractor aggregate output; and the saving of up to 25% of motor fuel.

Keywords: machine-tractor units, chisel tools, deep loosers, agrotechnical indicators, energy indicators.

INTRODUCTION

The systems of basic (fall) soil tillage need for improvement, because the intensification of agricultural technologies is accompanied by anthropogenic impacts on the soil due to the multiple passage of heavy vehicles across the field, which causes the compaction and overcompaction of soil horizons at depths to 1.2 m. The clay and loamy soils are compacted most intensively; the droughty climate and irrigation are additional factors increasing the soil density. High-technology agriculture is impossible without deep tillage as a kind of the basic tillage, i.e., the management of subsoil. This is an important agrotechnical challenge also aimed at solving the global ecological problems (Baba, [3]; Foley *et al.*, [12]; Reithmuller, [27]; Scheffer *et al.*, [32]; Smith, [33]; Vitousek *et al.*, [39]).

The plowing of soil with conventional moldboard plows at a depth of 0.20-0.30 m results in the formation of a plow pan (hardpan), which hampers the development of plant roots; the hardpan is also formed after the subsurface cultivation. The increase of the plow depth to over 0.30 m is inadvisable, because the draught resistance of the tillage implement radically increases; the droughty conditions and soil overcompaction (including due to irrigation) provoke the cloddiness of the soil surface.

The advisability and periodicity of the deep nonmoldboard plowing of subsoil are discussed in many countries. However, the presence or absence of subsoil cultivation depends on the needs of the cultivated crops, the soil type, and the densities of the plow and subsurface horizons. For most agricultural crops, the optimum soil density is ρ = 1.1-1.2 t/m^2, but for some of them, ρ = 1.3 t/m^3 (Kushnarev and Kravchuk, [20]; Pyndak *et al.*, [25]). There are supporters and opponents of deep soil tillage; the exclusion of any cultivation, also known as the no-tillage (NT) or zero-tillage technology, is widely discussed. The results of studying the NT and the conventional tillage (CT) technologies were compared by some authors (Amato *et al.*, [1]; De Vita *et al.*, [11]; Ruisi *et al.*, [29]). Nonetheless, the discussions usually do not touch the subsoil; the plow horizon to a depth of 0.30 m is the main object of study, and the crop yield is mainly assessed for spiked cereals, including wheat. However, wheat having a weak root system slightly responds to the increase of soil density to ρ = 1.3 t/m^3. The effect of deep tillage is manifested at the cultivation of row crops with deep roots.

Many authors (Angers *et al.*, [2]; Baker *et al.*, [4]; Daz-zorita, [9]; Lal and Kimble, [21]; Ruisi *et al.*, [30]; Salinas-Carcia *et al.*, [31]; Van Gaelen *et al.*, [37]; West and Post, [40]) emphasize the roles of nitrogen and dissolved organic carbon in the soil and their contents depending on the tillage practice. Land use, including tillage practice, becomes a global environmental problem, which hampers the human and ecosystem capabilities of sustaining the production of food (Clarke, [6]; Matson *et* *al.*, [23]; Scheffer *et al.*, [32]; Tilman *et al.*, [35]). In the United States, since the 1960s, special attention is given to the erosion and pollution of soil under cultivation, the important factors for which are the moisture content, structure, organic carbon content, and microbial activity of soil (Logan *et al.*, [22]).

Some tillage tools ensure the deep nonmoldboard loosening of different soil types; chisel tools best meet the current agrotechnical requirements (Borisenko, [5]; Pyndak *et al.*, [24]; Smith, [33]; Trufanov, [36]; Vetochin, [38]). Chisel implements are deep rippers ensuring the decompaction of subsurface horizons. The rational chiseling depth is 0.35-0.45 m; tools for relatively shallow (0.15-0.35 m) and overdeep (to 0.80 m) nonmoldboard tillage are also elaborated. Chiseling is a synonym of subsoiling.

After the basic soil tillage (usually in fall), the density of soil regularly decreases, especially after the conventional moldboard plowing (Figure-1). However, it increases again during the vegetation of plants, particularly also after the moldboard plowing (Kushnarev and Kravchuk, [20]; Pyndak *et al.*, [24]). Against this background, the deep nonmoldboard tillage is slightly related to the life cycles of soil and plants and can be considered compromise.

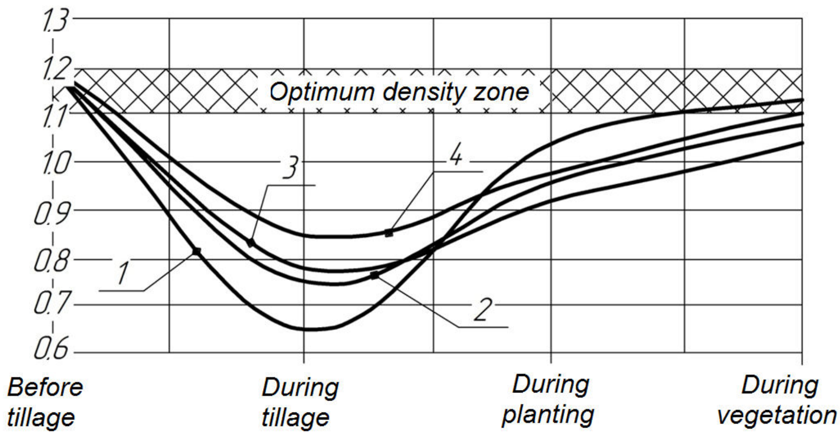

Figure-1. Soil density under different tillage practices: (*1*) moldboard plowing; (*2*) surface loosening; (*3*) disking; (*4*) nonmoldboard tillage (deep loosening).

The NT supporters believe that weeds should be controlled by chemical methods, and the incorporation of fertilizers into the soil to the target depth is not obligatory. This results in some shortfall in crop production, because the structure and water-air balance of the soil are deteriorated, the soil density increases (including under irrigation), and the activity of soil biota is reduced. Some specialists propose the deep nonmoldboard loosening of soil to be performed every three years.

The object of studying the soil density was mainly the plow horizon to a depth of 0.30 m, because density metamorphoses occur in this horizon (Figure-1). However, the changes of density and other parameters in the deep subsoil horizons also affect the vital activity of soil biota and the cycles of water and nutrients in the shallow horizons (Kushnarev and Kravchuk, [20]). The problem is solved only after the deep ripening to 0.35-0.45 m with the breaking of the hardpan. This is primarily true for the droughty regions, including under irrigation conditions (Ishaq *et al.*, [16]). It was found (Kuznetsov *et al.*, [19]) that the yield of green forage mixture increases by 8-12% after the deep tillage of loamy soils (under drip irrigation). In the presence of a compacted subsurface horizon, the irrigated soils are subjected to a number of negative factors: the coefficient of water filtration and the thickness of the root-inhabited zone decrease; water erosion and secondary salinization occur; etc. (Danatarov and Ashyrov, [8]).

Numerous publications on subsoil mainly deal with agronomic problems; technical means for deep tillage and decompaction (loosening) of soils and their potentials were episodically described (Baba, [3]; Constantin *et al.*, [7]; Smith, [33, 34]; Hipps and Hodgson, [13, 14]). Insufficient number of works deals with the energy intensity and energy efficiency of such tools, which affects their applications. The review should obviously be as comprehensive as possible.

MATERIALS AND METHODS

Chisel subsoilers were studied on the models created due to technical creativity and inventivity. In the studied modifications, the main principle of chisel operation was retained: the deep nonmoldboard loosening of the subsurface horizons by means of straight or slant shanks with chisel heads. The main refinements were aimed at expanding the performance potentials of tools and improving the agrotechnical parameters of tillage.

The experimental studies were performed on implements with 3-10 tillage tools for the basic (fall) tillage of light chestnut loamy soils and light loamy chernozems to a depth of 0.30-0.45 m under the droughty conditions of the Lower Volga region (Russia) with and

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without irrigation. The implements were aggregated with wheel and crawler tractors with a power up to 200 kW. The control studies were performed at the machine-testing stations in the southern Russia (Figure-2).

The power performances of the chisel tools of machine-tractor aggregates were determined by the measurements and interpretation of the following parameters: operating speed (km/h); average operating width (m); penetration depth of tillage tools (m); average tillage depth (m); field capacity (ha/h); motor fuel consumption rate (km/h); draft (kN); draft power (kW); power consumption (kW); specific energy consumption (kWh/ha); specific fuel consumption (kg/ha); capacity utilization factor; and driver slipping (%).

Figure-2. Machine-tractor aggregates with chisel tools.

Agrotechnical parameters were also determined, including the ridgeness of field surface; partial stubble retention; and the cloddiness, crumbling, loosening, ridgeness, and dispersion factors. Some of these parameters were determined for two types of chisel tools, with and without breasts on the shanks. The obtained results were compared (if possible) with the corresponding parameters of the machine-tractor aggregates with the conventional tools.

RESULTS

In Russia and Kazakhstan (then parts of the Soviet Union), the nonmoldboard tillage became the most acute problem after the development of virgin and fallow lands in the Transvolga and Northern Kazakhstan regions. The inadequate farming system involving the tillage of soil with conventional moldboard plows resulted in soil deflation and dust storms under droughty climatic conditions, as was subsequently generalized by Kiryushin [17].

For the solution of this vital problem, soil-tilling implements with working elements called SibIME shank cultivators (Figure-3, *a*) were developed and universally used. The SibIME shank cultivators are mounted on the frame of conventional equipment (in place of shares), penetrate into the soil to the same depth as the shares (0.24-0.28 m, sometimes to 0.30 m), and leave behind the same plow pan; they are used until now. However, these tools do not loosen the subsoil; they are not designed for the incorporation of bulk fertilizers, ameliorants, and organics and have an insufficient penetration depth.

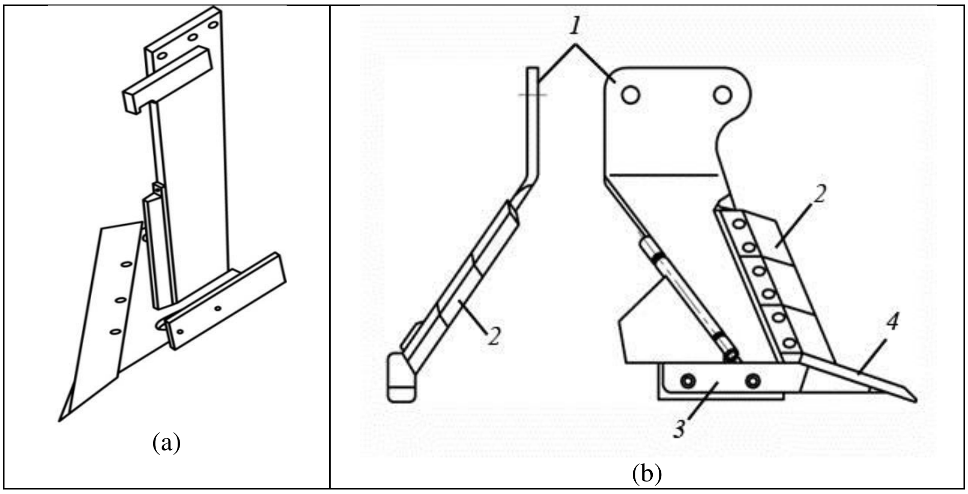

Figure-3. Prototypes of modern shank chisels: (*a*) SibIME shank cultivator; (*b*) American paraplow shank subsoiler.

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The American slant-shank subsoiler (Trade name, 'Paraplow') is the prototype of the modern chisel tools (Figure-3, *b*). The shank is angled (bent) and consists of leg 1 (mounted on the implement frame), surface-mounted blade 2, lower shoe 3, and removable chisel tip 4. The implement ensures the depth of subsoil loosening in a wide range. The shank angle is $\beta \approx 35°$, which is unfounded, in our opinion (see below).

In Russia, a range of soil-tilling chisel-type tools were developed, which consist of a straight (Figure-4, *a*) or slant (Figure-4, *b*) shank with a chisel head; a two-legged tool with one chisel head was recently developed (Figure-4, *c*). Regardless of the type and designation of the implement, the chisel component forms the ridged bottom of the furrow (Figure-4, *a-c*); the side views of these shanks are similar (Figure-4, *d*).

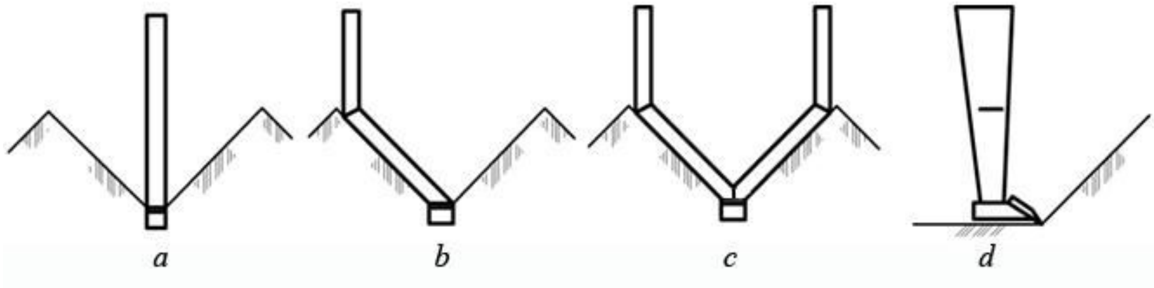

Figure-4. Diagrams of shank chisels and their interaction with the soil.

The specific furrow bottom (after chiseling) is well known and described, e.g., by Trufanov [36], but no unambiguous substantion of this phenomenon is available. Numerous experimental data show that the specific energy intensity of deep chiseling (to a depth of 0.50 m) decreases compared to the conventional moldboard tillage, which also finds no adequate substantiation.

The unconventional furrow bottom is characterized by the following geometric parameters (Figure-5): h, chiseling depth (preferably 0.32-0.42 m); M, distance between the chisel tracks ($M \approx h$); $2\beta \approx 90^o$, ridge angle; $B \approx 0.06$ m, local hollow width (chisel head width). On the sloped lands, the tillage across the slope is advisable (Figure-5). In these most common cases (there are almost no ideally flat fields), the soil water after rains and snowmelt is accumulated on the furrow bottoms, as well as organic particles and nutrients. This prevents the soil erosion by water and solves problems of water saving.

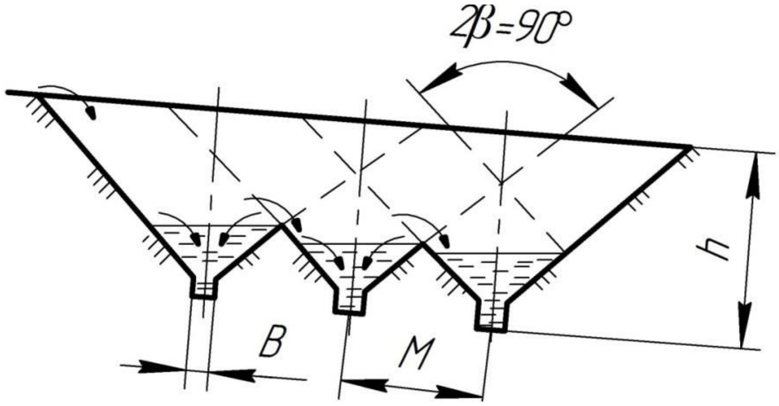

Figure-5. Chiseling and water retention on slopes.

It follows from Figure-4, *b* that the lower part of the slant shank slides along the ridge side; therefore, the weeds hanging after soil breakdown are combed out and get to the deeper horizons. In the two-legged tool (Figure-4, *c*), both ridge sides are combed. This positive event occurs, if the shank angle is $\beta = 45^o$, which is not the case for the American Paraplow subsoiler (Figure-3, *b*). The fact is that the angle of 45° approximately corresponds to the in-break angle or the natural soil slope.

Shank chisels ensure the nonmolboard loosening of soil with the preservation of up to 70% of stubble (and weeds) on the surface. This was earlier considered as an advantage of chiseling and a means for the retention of snow and the decrease of wind erosion. However, the preservation of most weeds results in the invasion of fields; in addition, the shanks are not customized for embedding bulk mineral and organic fertilizers and ameliorants into the soil. This problem is solved, if a special breast (but not share!) is mounted on the shank; work tools with breasts on straight or slant shanks are elaborated and used (Figure-6). A tube with a nozzle can be mounted on the backside of the shank for delivering liquid fertilizers and ameliorants to the target depth (the tube is shown by the broken line).

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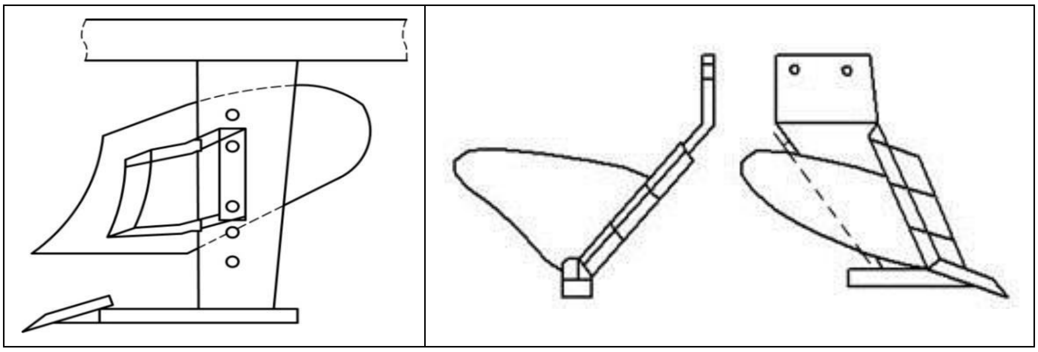

Figure-6. Straight and slant shanks with breasts.

The breast is mounted on the shank with the possibility of discrete vertical shift; the depth of its penetration into the soil is 0.15-0.20 m. The presence of breasts on the shanks affects the profile of chiseling (Figure-7); here, h_0 is the depth of the turned upper (loosened!) horizon. This ensures the inhibition of weeds and the optimum conditions for the burial of organics, fertilizers, and ameliorants and the stimulation of soil microbial activity. A method of chiseling with variable h_0 values for the neighboring shanks was developed. This makes a wavy tillage profile, which favors the retention of snow and reduces erosion. When unnecessary, the breasts are easily demounted.

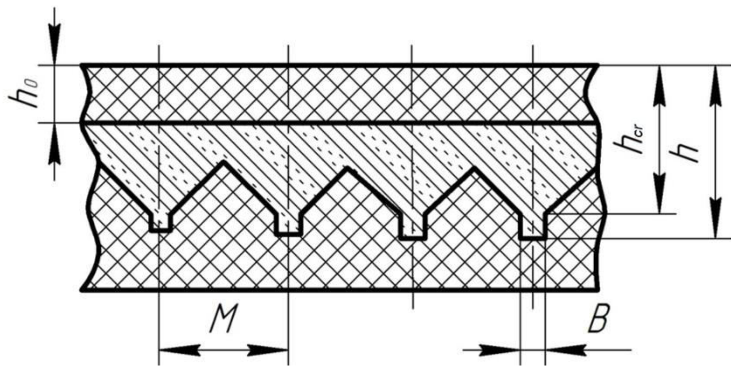

Figure-7. Profile of chiseling with a breast.

Under conditions of rational nature management, wide row planting with the use of the bottom features of chiseling furrows is promising (Kuznetsov *et al.*, [19]). For example, at the cultivation of grain corn (in dry and irrigated agriculture), it is advisable to arrange plant rows in every other furrow, with inter-row spacing $L = 2M = 0.8$ m (Figure-8). The root system of corn is responsive to the tillage depth and the water capacity of soil; it freely penetrates to depth h and into the subsurface horizon to provide additional water and nutrients. In the next year, the rows of plants are shifted by distance M and are located in the unoccupied furrows.

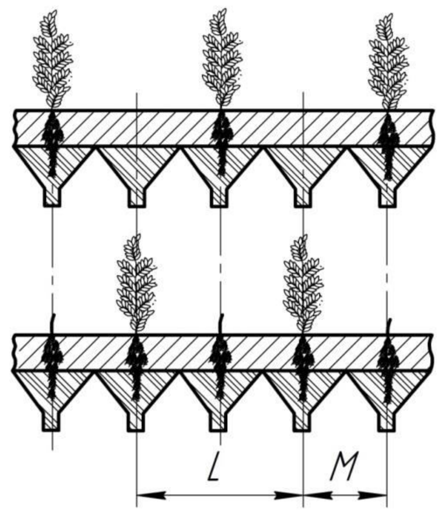

Figure-8. Pattern of corn planting in the first and second years.

The modifications of tillage implements based on chisel tools are aimed at expanding their functional capabilities and increasing the durability of working

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blades (Baba, [3]; Pyndak *et al.*, [24]; Pyndak and Novikov, [25]; Smith, [33, 34]; Vetochin, [38]). In particular, the straight shank is supplied with removable skim-colters for cutting weeds and ridge tops (Figure-9, a), as well as drains and additional rippers for the mole drainage of soil.

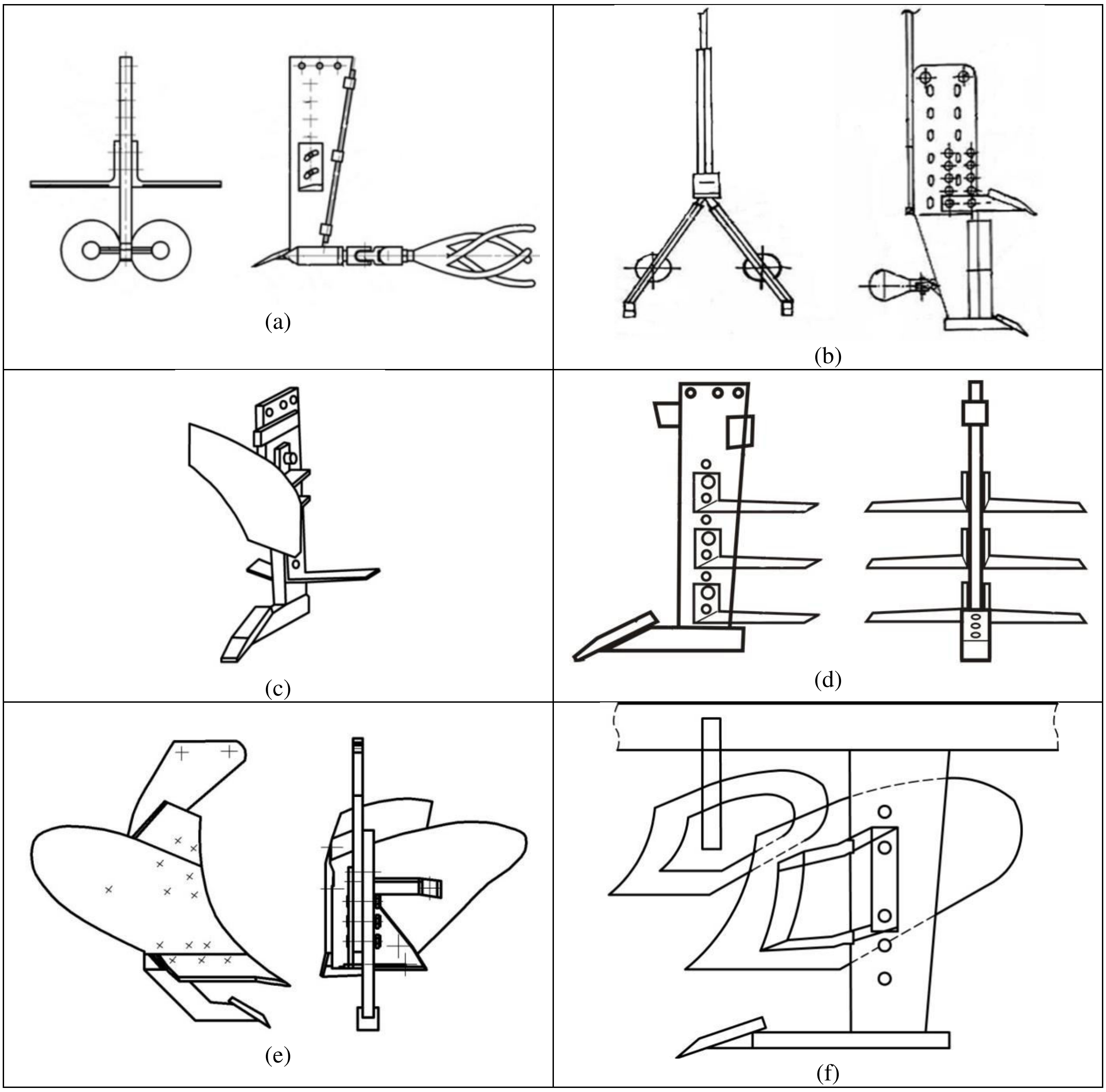

Figure-9. Modifications of chisel-based soil-tilling implements.

Double-deck work tools are used for the ultradeep (to 0.80 m) loosening (Figure-9, *b*): the upper deck is a straight-legged chisel; the lower deck consists of additional rippers (pan breakers with drains); the feeding of liquid ameliorants to the target depth is provided. In another version (Figure-9, *c*), the straight leg is supplied with a breast and flat blades. The chisel implement with three layers of blades (Figure-9, *d*) is mainly designed for the multiple cutting of the deep roots of weeds like bitterling.

A moldboard implement with a chisel pan breaker was also elaborated (Figure-9, *e*). It is characterized by the decreased energy intensity of tillage, because the share passes in the decompacted plow horizons (after chiseling). The combined chisel implement (Figure-9, *f*), along with the straight shanks with chisel heads, can be supplied with breasts and skim-colters. The tillage depth is 0.25-0.40 m; the complete removal of weeds and their incorporation into the soil are reached by the multiple loosening of the upper horizon.

An original arrangement of many (up to 10) slant shanks on the implement frame was proposed. The shanks are made in pairs, left and right, which allows their compact arrangement on a frame of limited size (Figure-10). The pair of these shanks is conventionally referred to

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as an X-shaped shank; in this case, two adjacent shanks enclose one furrow ridge.

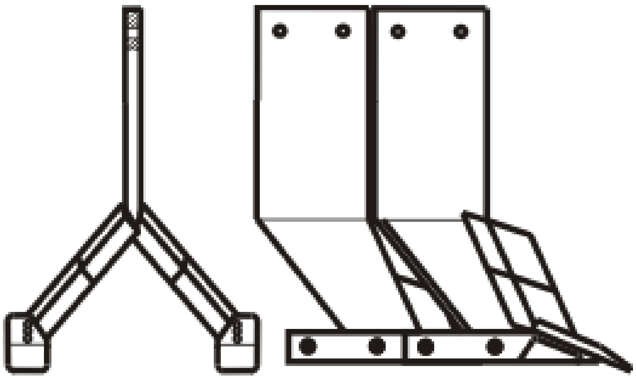

Figure-10. Compact arrangement of slant shanks on the frame (X-shaped shanks).

Industrial tests were also performed on 10- and 8-shank chisel implements with X-shaped shanks (Figure-2). Extracts from test reports are given in Table-1 (Borisenko, [5]); it can be seen that the integrated parameters of the machine-tractor aggregate (MTA) with an 8-shank implement are better for draft (by 41.9%), power consumption, specific fuel consumption, specific energy consumption, and driver slipping (by 2.24 times). This shows that the number of work tools (shanks) should be selected individually for each tractor. However, the integration of the implement (mounting and demounting of the shanks) is a simple task.

Table-1. Agrotechnical and energetic parameters in the tests of MTAs with chisel implements.

Parameter	Values	
	10 shanks	**8 shanks**
Operating speed, km/h	6.6	8.6
Averageoperatingwidth, m	3.81	3.10
Penetration depth of tillage tools, cm	40-45	40-45
Average tillage depth (behind chisel head), cm	42.19	43.12
Ridgeness of field surface, cm	6.6	6.7
Stubble retention, %	76.26	61.62
Sticking and plugging of tools	not observed	
Field capacity during the productive labor, ha/h	2.74	2.67
Fuel consumption during the productive labor, kg/h	49.2	45.6
Draft, kN	58.6	41.3
Draftpower, kW	117.2	98.7
MTA power consumption, kW	188.5	166.9
Specific energy consumption, kWh/ha	68.80	62.51
Specific fuel consumption during the productive labor, kg/ha	17.96	17.08
Engine capacity utilization factor	0.95	0.84
Driver slipping, %	13.0	5.8

Revealing results were obtained in the comparative operational tests of a 5-shank chisel implement with slant legs (with and without breasts), a comparable 4-furrow moldboard plow, and an implement with 4 SibIME shank cultivators; the implements were aggregated with a crawler tractor (Figure-2). The results of tests (Table-2) show that the chisel implements exceed the serial implements in all parameters, including field capacity and specific fuel consumption.

Table-2. Comparative operational tests of implements.

Parameter	PN-4-35 plow	Plow with SibIME shanks	PVCh-5-40 chisel	Chisel with breasts
Specific metal content, kg/m	500	478	280	305
Field capacity, ha/h	0.83	0.90	1.13	1.10
Specific fuel consumption, kg/ha	17.88	17.73	14.60	14.80
Running speed, km/h	5.94	6.41	5.65	5.40

Comparison data obtained for the quality parameters of basic tillage (Table-3) confirm the advantages of the chisel implements.

Hipps and Hodson [13, 14] showed that loosening by a slant-shank Paraplow increases the amount of winter-wheat roots; the profitability of the first and second yields increases by 0.65 t/ha at the same seeding rate. On the second field, where barley was cultivated, a decrease of soil density was recorded at a tillage depth of 0.33-0.35 m. On the third field, the germinating ability of seeds and the profitability of spring barley growing significantly increased at an average yield of 2.70 t/ha.

Ishaq *et al.* [16] studied the growing of wheat and cotton on irrigated sandy loams in the semiarid region of Pakistan and found that the porosity of soil remains for 3-4 years after subsoiling. The main effect of chiseling was the decreased removal of nutrients from the soil: N by 11-16%, P by 11-15%, and K by 5-10% (after wheat growing); a slightly lower effect was also recorded after cotton growing. Some saving of irrigation water was also achieved.

Table-3. Quality parameters of basic soil tillage.

Factor of	PN-4-35 plow	Plow with SibIME shanks	PVCh-5-40 chisel	Chisel with breasts
Cloddiness	70.5	66.8	60.5	61.5
Crumbling	33.8	55.4	63.4	62.5
Loosening	25.5	28.8	26.7	27.2
Surface cloddiness	40.0	12.5	11.6	17.0
Ridgeness	24.7	16.2	7.4	17.8
Dispersion	1.7	1.4	0.5	1.2

A limited number of works deal with the design of chisel implements. The interaction of the chisel head with the soil, as well as the physicochemical principles of subsoiler design, is considered in the available literature (Koolen and Kuipers, [18]; Vetochin, [38]). It is declared (Ros *et al.*, [28]; Dechao and Yusu, [10]) that the mathematical simulation and computer-aided design were performed, and the dynamic models of some soil-tilling tools were developed. Such theoretical studies can be used for the development of chisel-subsoiler design techniques. However, the theory of soil chiseling and the energy efficiency of deep subsoiling are still to be developed and substantiated.

DISCUSSIONS

Chisel tools and implements are not considered as a separate class of technical means for soil tillage. Most works are published under the heading: Subsoilers (Baba, [3]; Hipps and Hodson,[13, 15]; Reithmuller, [27]; Vetochin, [38]). Russian authors prefer the terms of chisel tools and chiseling (Borisenko, [5]; Pyndak and Novikov, [25]; Trufanov, [36]), chiseling being the nonmoldboard ripping or decompaction of deep subsurface horizons. Later on, chisel tools were also used for relatively shallow cultivation (at 0.15-0.35 m). A tendency is observed of using chisels in combination with other tools in hybrid implements; an example of such combination is provided by a conventional share and a chisel pan-breaker mounted on the same leg (Figure-9, *e*). The development of multifunctional soil-tilling implements is also planned (Constantin *et al.*, [7]).

The cited papers mainly discuss the potential of chisel subsoilers as means for increasing the farming efficiency, when appreciable results are reached due to the stabilization of organic carbon and nitrogen in the soil. However, not only the C and N contents are of importance for the plow and subsurface horizons, but also the C:N ratio, the optimum value of which is in the range between 24 and 32 (Borisenko, [5]). It is known that organic carbon favors the increase in the content of humus in the soil. The closed cultivation of soil with slant-shank chisel implements hampers the removal of the carbon bearer (gaseous CO_2) by 3.2 times compared to the conventional tillage practice.

The role of chisel implements in the increase of soil porosity and the corresponding decrease of its density to a rational level (ρ = 1.1-1.3 t/m^3), which remains for 3-4 years, is also emphasized. Numerous publications confirm the increase of crop yields after chiseling. Of some surprise is the role of chisel implements in the decrease of density of loamy soils, the increase of forage crop yields, and the saving of water in irrigation agriculture (Kuznetsov *et al.*, [19]); this is confirmed by the studies performed in Pakistan with the growing of wheat and cotton as an example (Ishaq *et al.*, [16]).

The interaction of the chisel head with the soil results in the formation of a ridged furrow bottom. The known studies (not given) showed that the intrasoil ridgeness disappear when the chisel head is displaced by a narrower tool, which converts the chisel implement to a paraplow; no ridges are also formed at the ultradeep chiseling (deeper than 0.6 m). This implies that the effect of chiseling is manifested under specific conditions. Ridges at the angle $\beta \approx 45°$ ($2\beta \approx 90°$ at the ridge top) result from the breakdown of soil in front and at the sides of the chisel head (partially shown in Figure-4).

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In distinction from the moldboard and subsurface plowing, chiseling results in only a local deformation of soil (around the chisel head), and the loosening (decompaction) of the bulk soil is mainly due to soil breakdown. Consequently, the specific energy intensity of tillage decreases: the average operating width and, hence, the MTA field capacity increase at the higher penetration deep of work tools than in the conventional tillage practice; the specific consumption of motor fuel decreases by 20-23% (Table-2). Therefore, the chisel tools and implements are energy efficient (Pyndak and Novikov, [26]).

The performance parameters of the basic soil tillage by means of chisel implements with and without breasts were determined for the first time (Table-3) (Borisenko, [5]). Of highest interest is the radical decrease (by 3.5 times) of cloddiness on the soil surface after chiseling compared to the moldboard tillage, as well as a significant increase in the crumbling of soil aggregates.

CONCLUDING REMARKS

The introduction of chisel tools and implements into the farming practice will solve some problems related to the degradation of soils of different compositions in different states, including the decompaction of soils on the fields subjected to the anthropogenic impact of heavy vehicles and the control of soil erosion by water and wind. The highest effect of chiseling is reached on loamy soils under arid and semiarid conditions, in the absence or presence of irrigation. The efficiency of chiseling is manifested at different depths, but especially at 0.35-0.45 cm with the breaking of the hardpan. Deep ripening and decompaction of the subsoil also have a positive effect on the conventional plow horizon to a depth of 0.30 m. Chiseling favors the accumulation of organic carbon and nitrogen in the soil and stimulates the preservation of humus; the decrease of N, P, and K removal; the saving of irrigation water; and increase in the yields of some crops.

The modernization of chisel tools, in particular their supplement with special breasts (but not shares), expands the functional potentials of the implements and ensures the embedding of weeds, organics, and bulk fertilizers into the soils; the feeding of liquid fertilizers and ameliorants to the target depth is also provided. In spite of the increase of the tillage depth, the field capacity and energy efficiency of the chisel implements increase; this provides new opportunities for their application. In a modification, the traditional moldboard tool is supplied with a chisel pan-breaker; thus, the share moves in the decompacted soil, and the energy intensity of tillage decreases by up to 30%.

In the generalized form, the chisel tools and implements are means for solving the following problems: the breaking of hardpan and the decompaction of subsoil for 3-4 years; the decrease of organic carbon and nitrogen losses; some stabilization of the C:N ratio; the decrease of N, P, and K removal and humus loss from the soil; the increase of productive water supply in the soil (down to a depth of 0.45 m) and the improvement of the air–water conditions in the plow and subsurface horizons; the prevention of soil erosion by water and partially by wind; the development and deepening of plant roots; possibility for the transformation and modernization of work tools; the improvement of the quality parameters of basic tillage and, primarily, the reduction of cloddiness on the soil surface after tillage; the increase of the MTA field capacity and the saving of up to 25% of motor fuel; the increase of the efficiency of both dry and irrigated farming; some increase in the yield of crops; and the saving of irrigation water.

The above-discussed parameters of chisel implements and soil chiseling are of integrated character; they emphasize the advantages and potentials of subsoilers.

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