Modular load-bearing structures for the study of interactions between the soil and working parts of agricultural machines

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Abstract. The authors outline in this article the principles underlying the conception and design of modular load-bearing structures (MLBS) for the study of the interaction between soil and the agricultural machinery working bodies for the inter-study study of 3D CAD design. It presents the main scientific problems faced by agricultural machines for soil works, main reasons for the conception and realization of this machine or category of machines. It also presents the scientific but also economic reasons for the modulation or modular design of this machine, an operation that has led to several possible working variants, which require power sources for traction of different values. It also presents the multifunctionality acquired through the possibility of using work parts and their supports of different types and mountable on the structure in different formations.

1. Introduction

Soil processing by mechanized parts in agriculture is a very old practice, especially if we include in this also the traction with animals of some elementary agricultural machines (the first plough, for example according to [1], [2], can be dated 4000 - 6000 years ago). There are opinions that assert that important changes in the structure of the soil tools, mark important stages in the history of humankind: "And if, in the chaotic unfolding of the events that surrounded the end of antiquity and the beginning of the Middle Ages, it would have been necessary to find a symbol that marks opening a new era, you may not be able to choose better than the invention of the plough", [3]. According to [4], "Mechanisation of agriculture is fundamental to reducing poverty and improving lifestyle and food security in the developing world. Large populations are escaping subsistence agriculture, and there is a broad consensus that conservation agriculture (CA) is the only sustainable approach to cropping. Equipment for CA could be a major focus of R&D activity by the global farm machinery industry, but this is not happening."

Although the practices of soil works have a long tradition, basic problems have remained permanently in attention: determining with the best approximation of the draft force, optimizing the working process, improving the use of the power source, reducing the wear. These issues have long been addressed in the literature, [5-8]. In the last half century new directions have emerged, highlighted by the consequences of the classic works of the soil on the environment, especially the soil. No-Tillage and Conservation Tillage cultivation technologies, have been a growing success.

Our main objectives in research were:
- investigating the possibility of estimating with great accuracy the draft force on the forward direction and possibly on the other two directions perpendicular to the forward direction;
- estimation of the effect of the density of working parts on the total force of draft force;
- the systematic variation of the draft force between the working bodies placed in different places on the load-bearing structure;
- the most efficient use of the power source (usually the tractor, in case of soil tillage machines).

Modulating agricultural machines is not a new idea. However, the physical achievements on a 1:1 scale of this type are rare. From modern literature we mention, [9-13]. Modular design is a common notion in many fields of technology and industry, especially in developing industries, [14]. According to [15], modular design is a recognized technique for organizing and simplifying complex systems. From the component parts, the elementary ones, to the complex ones, the modular design has demonstrated an efficiency that cannot be doubted. Also in [15] it is shown that originally, the term modular design refers to an innovative method for the design of complex products. These ideas find their theoretical foundations in the works of some authors after the 1960s, for example [16]. According to [17], modular design, or modularity in design, is an approach (design theory and practice) that subdivides a system into smaller parts called modules, which can be created independently, modified, replaced or exchanged between different systems.

The modular design has been developed mainly in the area of the transport industry, [18-20] and in the area of civil constructions. Modulated tractors are a common presence in the agricultural landscape and forestry, but the range of such machines (agricultural robots, etc.) is constantly improving, [21]. Agricultural constructions such as greenhouses are the subject of modulation being able to make greenhouses, zootechnical constructions of desired size, agricultural halls quickly and easily assembled and removable for example, [22-24]. At the top of this pyramid of development through modular design, in agriculture, it seems that there is what is called vertical farming, [25-27]. Modulated structures are already enshrined in agriculture in large irrigation systems (wings and modulated systems) and in energy systems of solar panels, [28]. However, even in the area of transport vehicles, the agricultural mechanization has designed trailer tractor systems with several trailers, a first modulated system. In the 1980s, at the INMA Bucharest, a modulated combination was designed and built, capable of harvesting various types of cereals by changing the header and some processing elements of the harvested material. The wide range of machines destined for the mechanization of small farms, has led to the design of power sources (tillers, mini tillers, rotavator cultivator, etc.), which can operate devices for working the soil, harvesting, sprinkling and other operations, [13], [17]. Modular design is involved today in areas related or apparently with weak links, but of great interest, such as the architecture and cultivation of vertical agricultural production, [29], and [30]. Literature dedicated to modularizing design in various fields has proliferated over the last 20 years: [31-36]. Obviously, review articles have also appeared on this topic, [37]. Modularization is a general current in the practical science at present, settling comfortably in the conception and design of software, in the conception and elaboration of the education systems, health, etc.

Therefore, designing a modulated and multifunctional structure, we have only tried to use new practices and theories in making a product with multiple utilities, in related fields. Specifically, we tried to design a modulated load structure for agricultural machines to work the soil, useful primarily for research but also for production. The modularization of this structure is useful not only for realizing necessary configurations in the investigation of the phenomenon of the interaction between agricultural machine and soil, but also in production, where, by using certain working configurations, the machine adapts to the requirements of the beneficiary related to the workspace, and to the power source available.

2. Modular load structure with multiple applications

In order to study the main problems proposed in the research program, it was proposed to design a load-bearing structure capable of supporting small and medium-depth working parts, which develops corresponding forces, so that the uneven characteristics of the soil are as high as possible attenuated.
The modulation of the load-bearing structure was based on the following three requirements:
R1) the load-bearing structure must ensure the realization of as many variants of distribution of the work parts linked by removable supports, in order to investigate how the density of the work parts contributes to the variation of the intensity of the total tensile strength, the variation of the quality of the soil work and other important features of the working process of the machines intended for soil works;
R2) the load-bearing structure must be able to work in various possible variants, which simulate situations characteristic of large or small agricultural farms, available power sources, economic resources (different working widths for small and medium power tractors);
R3) the structure was designed for research, but it can also be used for practical purposes, in production, its modularity is helping to achieve this goal.

These three requirements have crystallized in time, in the process of conception. The beginning was with the first requirement, R1, then, taking into account the existing resources, the requirement R2 appeared. Finally, considering the real time of use of agricultural machines of this type and the fact that for the research, the request of the structure does not lead to the satisfactory efficiency of its use, the third requirement R3 appeared.

The basic concept of the MLBS structure is shown in Figures 1, 2 and 3. The images in Figures 1, 2 and 3, they reproduce exactly sketches with information about the functionalities of the supporting structure. The working parts are represented by arrows only for the nearest row of working bodies from the tractor, in order not to load the images and to be easier to understand to the readers. Dimensions a, b, c, d and e are fixed during the design process. These dimensions take into account the possibility of working the side wings separately, each with low value power sources. At the same time, the use of wings in the role of small cultivators on agricultural areas of small width, such as narrow rows of vines, is also considered.

Figure 1. Modular load-bearing structures (MLBS) in working formation with maximum working width - Top view –
Therefore, the concept of modulated load-bearing structures (MLBS) shown in Figures 1, 2 and 3 is based on modules and are multifunctional. In principle, the structure has three distinct working modules that can each function separately as a cultivator, for two working widths (the side wings have the same working width, for symmetry reasons).

3. Results and discussions

The modulated load structures (MLBS) are designed for complex researches of the interaction of agricultural machines intended for soil works and are based on the general schemes in Figures 1, 2 and 3. The main component parts, modules, of the MLBS are (see Figure 4):

- the central framework (CF);
- left side frame (wing) (RF);
- right side frame (wing) (LF);
- the traction triangle for the wings is visible in Figure 5, for the left side frame, LF (similar for the right side frame RF).

As can be seen in Figure 4, in the initial design there are two reinforcement traverses in the CF, with the terminal part oblique to the frame bars. By a suitable choice and estimation of the efforts in the structure during the pre-design structural analysis stage, they were eliminated, using corresponding profiles of the bars that support the working parts. Through this operation, a distribution of the working parts could be realised taking into account the real working processes, in which, in the field, there are vegetal debris. Vegetal debris can agglomerate and disrupt the working regime, affecting the quality of the work (especially the working depth).

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1 We do not exclude the creation of a load-bearing structure of the type shown in Figures 1, 2 and 3, with non-symmetrical side wings (as working width), in order to achieve three possible working widths. But the idea complicates the execution and calculation of resistance, as well as the dynamic behavior of the structure.
Figure 4. Modular load-bearing structures (MLBS) - Initial architecture, resulting from the design process

Figure 5. Modular load-bearing structures (MLBS) - left side frame (LF), equipped with the tractor coupling triangle
The left side frame together with the tractor coupling triangle is shown in Figure 5. In the initial conception, the traction triangle of each of the side frames is removable, so that, in working in the total ECC structure, they are not left mounted on the side frames.

Modular load-bearing structures (MLBS) are provided so that they can work in four working variants:
- Maximum working width variant, noted LFCFRF (working width: approximately 4 m);
- The LFRF variant, obtained by direct coupling of the wings (elimination of the CF central frame), Figure 6 (working width, about 2 m);
- Variant central frame without wings, CF (working width, about 2 m);
- Simple wing variant, LF or RF (working width, approximately 1 m).

Obviously, the traction requirement for each working variant differs and in this way the structure can be adapted to the availability of the traction powers of the beneficiaries. Also, with a variant with only one wing used as a ground work machine, the structure can also be used in narrow places such as vineyards. The working bodies in mobile assembly allow realizing a large number of variants of working distances between the working bodies. Also the structure will be able to work at different working depths.

![Figure 6](image)

**Figure 6.** Modular load-bearing structures (MLBS) - the LFRF working variant resulting through modulation

The MLBS can acquire increased multi-functionality if the working widths a, b are so designed and calculated that it can enter, in different working variants, at least on two standard types of vine plantations, according to the distance between rows (for example 2.0-2.2 m or 1.2 - 1.4 m between rows, according to [38] or 1.8 - 2.2 m, respectively 1.6 - 1.8 m).

In Figure 7 the technical drawing of the working module (working variant) CF is given, with corresponding supports mounted to achieve the working distance of 100 mm between two rows (400 mm between the median planes of two consecutive supports on the same transversal bar, perpendicular to the forward direction).
In Figure 8 the technical drawing of the complete working variant of the MLBS is given, with corresponding supports mounted to achieve the working distance of 100 mm between two working bodies (mounted according to the rule described in the previous paragraph). We mention once again that the supports and working parts are mounted on the load-bearing structure so as to optimally allow the release of the vegetal debris.

**Figure 7.** Modular load-bearing structures (MLBS) - CF working variant with supports of the chisel type working parts mounted on the structure

**Figure 8.** Modular load-bearing structures (MLBS) - the complete working version with the supports of the mounted working parts
4. Conclusions
The application of modular design in the field of load-bearing structures of agricultural machines intended for soil works tries to recover little of the land lost by this branch of the engineering design in relation to those of agricultural transports, agricultural constructions and agricultural tractors and robots.

The modulation of the load-bearing structures of agricultural machines intended for soil works confers a multiple functionality. Depending on the surfaces on which the modulated variants can be used, the following work possibilities emerge:

- on large and medium surfaces with high power tractors, the complete MLBS working variant is used;
- on medium and small surfaces with medium power tractors, the CF working variant is used;
- LFRF working variant is used on medium and small surfaces with medium power tractors;
- LF or RF working variant is used on small surfaces with low power tractors;
- increasing the number of variants mentioned above by diversifying and replacing the working parts, depending on the agronomic requirements;
- superior use of modulated load-bearing structures (MLBS), leads to an increase of the operating life, by using the variants for which there is a working front.

The functional features presented above, show that the designed structure is capable of meeting the research work requirements for investigating complex problems: checking the traction resistance according to the number and geometry of the location of the working organs on the structure, checking the real stress in the support of the parts working according to their location on the structure, the effect of increasing the density of working parts on the resistance force to traction, the effects of working depth and its uniformity for resistance to traction, researching the effects of the working regime parameters (speed, depth and working width, moisture and structural physical and chemical soil, etc.) on soil quality work.

The designed structure is always possible to be taken over in production, it is not designed for research purposes only, and the estimation of the power sources needed for each case of work formation (variant) will be made within the structural analysis phase in the pre-execution phase.

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