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SOIL-CLIMATIC CONDITIONS OF THE COTTON-GROWING REGIONS OF UZBEKISTAN AND THEIR IMPLICATIONS FOR THE DESIGN REQUIREMENTS OF A ROW-CROP TRACTOR WITH A TRANSFORMABLE CHASSIS

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Abstract. *Compaction of cultivated soil by agricultural tractors is one of the main technogenic pressures on soil fertility, and it is especially damaging under the arid, irrigated conditions of Uzbekistan. A tractor with a transformable chassis, in which the clearance, track width and wheelbase are changed by repositioning the support wheels, can reduce this pressure and extend the working season, but its design must rest on a description of the operating background. This article reviews the soil-climatic and agro-technological conditions in which such a machine will work. Starting from the typical technological maps for cotton, we describe three agro-technological zones, which differ in slope, precipitation, salinity and the pre-sowing operations they require, and we relate them to the two geographic zones that cover 71.7 % and 28.3 % of the national territory. On this basis, five cotton-growing regions, Khorezm, Bukhara, Kashkadarya, Tashkent and Namangan, were selected for laboratory-field research. We then identify the field properties that matter most for running-gear design (surface relief, soil moisture, hardness and density) and translate the zonal differences into qualitative requirements for a transformable chassis. The analysis provides a basis for specifying adjustment ranges and operating regimes of a universal row-crop tractor for year-round, all-weather use.*

Аннотация. *Уплотнение обрабатываемой почвы тракторами относится к числу главных техногенных факторов, снижающих плодородие, и особенно опасно в засушливых условиях орошаемого земледелия Узбекистана. Трактор с трансформируемой ходовой системой, у которого клиренс, колея и база изменяются за счёт перестановки опорных колёс, способен уменьшить это воздействие и продлить период рабочего сезона, однако его конструкция должна опираться на обоснованное описание фона, на котором он будет работать. В статье рассматриваются почвенно-климатические и агротехнологические условия эксплуатации такой машины. Исходя из типовых технологических карт возделывания хлопчатника, описаны три агротехнологические зоны республики, различающиеся уклоном поверхности, количеством осадков, засолением и составом предпосевных операций, и показана их связь с двумя географическими зонами, занимающими 71,7 % и 28,3 % территории страны. На этой основе для лабораторно-полевых исследований отобраны пять хлопкосеющих областей: Хорезмская, Бухарская, Кашкадарьинская, Ташкентская и Наманганская. Далее определены свойства поля, наиболее важные для проектирования ходовой системы, – рельеф поверхности, влажность, твёрдость и плотность почвы, – а зональные различия переведены в качественные требования к трансформируемой ходовой системе. Результаты анализа создают документированную основу для определения диапазонов регулирования и режимов эксплуатации универсально-пропашного трактора круглогодичного всепогодного применения. Предложенный подход позволяет сопоставлять результаты по областям и корректно переносить их на другие хлопкосеющие регионы с аналогичными условиями.*

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Особое внимание уделено влиянию давления в шинах, массы и скорости движения на уплотнение почвы.

Annotatsiya. *Qishloq xo‘jaligi traktorlari tomonidan ishlov beriladigan tuproqning zichlanishi tuproq unumdorligiga ta’sir etuvchi asosiy texnogen omillardan biri bo‘lib, O‘zbekistonning qurg‘oqchil va sug‘oriladigan dehqonchilik sharoitida ayniqsa xavflidir. Tayanch g‘ildiraklarining o‘rnini o‘zgartirish orqali klirens, izi va bazasi o‘zgartiriladigan transformatsiyalanuvchi yurish tizimli traktor bu ta’sirni kamaytirishi va ish mavsumini uzaytirishi mumkin, biroq uning konstruksiyasi ishlash fonining asosli tavsifiga tayanishi lozim. Maqolada bunday mashina ishlaydigan tuproq-iqlim va agrotexnologik sharoitlar ko‘rib chiqiladi. Paxta yetishtirishning namunaviy texnologik xaritalaridan kelib chiqib, respublikaning qiyaligi, yog‘in miqdori, sho‘rlanish darajasi va ekish oldi ishlari bilan farq qiluvchi uchta agrotexnologik zonasi tavsiflangan hamda ularning mamlakat hududining 71,7 % va 28,3 % qismini egallovchi ikkita geografik zona bilan bog‘liqligi ko‘rsatilgan. Shu asosda laboratoriya-dala tadqiqotlari uchun beshta paxtachilik viloyati – Xorazm, Buxoro, Qashqadaryo, Toshkent va Namangan tanlab olindi. Keyin yurish tizimini loyihalash uchun eng muhim dala xossalari – sirt releyfi, tuproq namligi, qattiqligi va zichligi – aniqlanib, zonalar o‘rtasidagi farqlar transformatsiyalanuvchi yurish tizimiga qo‘yiladigan sifat talablariga aylantirilgan. Tahlil natijalari yil davomida, har qanday ob-havoda ishlaydigan universal qator oralig‘iga ishlov beruvchi traktorning rostlash diapazonlari va ish rejimlarini belgilash uchun hujjatlashtirilgan asos yaratadi. Taklif etilgan yondashuv natijalarni viloyatlar bo‘yicha taqqoslash va ularni o‘xshash sharoitdagi boshqa paxtachilik hududlariga to‘g‘ri ko‘chirish imkonini beradi. Shuningdek, shinalardagi bosim, massa va harakat tezligining tuproq zichlanishiga ta’siriga alohida e’tibor qaratilgan.*

Keywords: *transformable chassis; row-crop tractor; soil compaction; agro-technological zoning; cotton; Uzbekistan; soil-climatic conditions; field relief.*

Ключевые слова: *трансформируемая ходовая система; универсально-пропашной трактор; уплотнение почвы; агротехнологическое зонирование; хлопчатник; Узбекистан; почвенно-климатические условия; рельеф поля.*

Kalit so‘zlar: *transformatsiyalanuvchi yurish tizimi; universal qator oralig‘iga ishlov beruvchi traktor; tuproq zichlanishi; agrotexnologik zonalashtirish; paxta; O‘zbekiston; tuproq-iqlim sharoiti; dala releyfi.*

Introduction. Agriculture in Uzbekistan is, to a very large extent, irrigated agriculture. Rainfall over most of the cultivated area is too low and too unevenly distributed to support a crop without water delivered through canals and furrows, and the land and water resources on which production depends are limited. Under such conditions the soil is not merely a medium in which plants grow. It is a store of moisture and nutrients, a filter for irrigation water and, once its structure has been damaged, a resource that is slow and costly to restore. Any technology that is introduced into the fields therefore has to be judged not only by its productivity but also by what it leaves behind in the soil.

Cotton remains one of the principal crops of the republic, and its cultivation is among the most mechanised of agricultural activities. A single season includes primary tillage, levelling, pre-sowing preparation, sowing, repeated inter-row cultivation, fertilising, plant protection and harvesting, and almost every one of these operations is carried out by a tractor or a tractor-drawn implement. Each pass transfers the weight of the machine to the soil through a small contact area. When the passes are repeated, and when they take place at unfavourable moisture, the soil is compacted, its porosity falls, its capacity to take in and retain water deteriorates and root growth is restricted. These are the processes that ultimately show up as lower and less stable yields.

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The problem is aggravated by the way in which conventional tractors are built. A wheeled tractor of a fixed design has a fixed clearance, a fixed track and a fixed wheelbase, and these dimensions are a compromise between very different tasks. The track that suits inter-row cultivation of a row crop is not necessarily the one that gives the best stability on a slope or during transport, and the clearance that allows the machine to pass over tall plants may raise the centre of gravity and reduce stability. A chassis that can be transformed, that is, one in which the clearance, track width and wheelbase are adjusted by changing the position of the support wheels relative to the vertical, longitudinal and transverse axes of the tractor, offers a way of resolving this compromise instead of accepting it.

The idea is attractive, but it raises an obvious question: what should the adjustment ranges and operating regimes of such a chassis be? The answer cannot be derived from the machine alone. It depends on the soils, the climate, the relief of the fields, the crop technology and the time windows in which operations must be completed, in other words on the background against which the tractor will work. The purpose of this article is to describe that background for the cotton-growing regions of Uzbekistan and to show how it can be turned into requirements for the design of a universal row-crop tractor with a transformable chassis intended for year-round, all-weather use.

The article is organised as follows. Section 2 summarises the relationship between the running system and the soil and explains why transformability matters. Section 3 presents the agro-technological zoning of the republic that underlies the typical technological maps for cotton. Section 4 describes the geographic zones of the country, and Section 5 explains how five regions were selected for laboratory-field research. Section 6 identifies the soil and field properties to be characterised, Section 7 translates the zonal differences into requirements for the chassis, and Sections 8 and 9 discuss the limits of the analysis and summarise the conclusions.

The running system and the soil: why transformability matters

The analysis of published research on tractor–soil interaction shows that a limited number of directions dominate the field. The first is the study of agro-climatic zones and of the soil-climatic conditions in which machines operate. The second is the determination of the physical and mechanical properties of soils, since these determine how a given load will be carried and dissipated. The third is the assessment of how the running system of a tractor affects the condition of the soil cover, and the fourth is the development of design solutions that reduce its negative effect on soil and plants. These directions are not independent. A design solution can be judged only against the soil conditions for which it is intended, and soil conditions can be described usefully only if the indicators selected are those to which the running system is actually sensitive.

The load applied to the soil depends on several factors that the designer and the operator can influence. The type of running gear, the width of the tyres and the air pressure in them determine the size of the contact patch and therefore the pressure exerted on the surface. The mass of the tractor and of any mounted or trailed implement determines the total load. The travel speed influences both the duration of loading and the dynamic component of the load, which grows when the machine moves over an uneven surface. None of these variables acts in isolation: a heavier machine on wide tyres at low inflation pressure may be gentler on the soil than a lighter one on narrow, highly inflated tyres, and the same machine may be harmless on a dry, firm field and damaging on a wet one.

Two groups of measures are generally regarded as the most effective ways of controlling this interaction. The first group concerns operating practice: regulating the air pressure in pneumatic tyres to match the load and the soil condition, and choosing a speed that is consistent with the agrotechnical operation and with the state of the surface. The second group concerns design, and it includes adaptive modifications of the running system. Among these, the ability to regulate the clearance, the track and the wheelbase by transforming the chassis from one

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configuration to another is especially promising, because it allows one machine to adopt the geometry appropriate to the operation rather than the geometry fixed at the factory.

The benefits of such adaptation are not limited to soil protection. When the position of the support wheels can be changed, the machine can pass between rows without damaging plants and without driving the wheels over the rows' protective zones, it can be made more stable on slopes and in transport, and its manoeuvrability and controllability in both field and transport work can be improved. Flotation and tractive properties on weak soils may also be better, because the wheels can be positioned so as to avoid repeatedly following the same track. For these reasons the transformable chassis is best seen as a means of widening the range of conditions in which one energy source can perform the entire cycle of technological operations.

It follows that the creation of a universal energy unit able to perform that entire cycle is possible only if scientifically grounded requirements for the transformable chassis have first been formulated. Such requirements cannot be taken from handbooks written for conventional tractors, because the adjustment ranges are new design parameters. They must be derived from the properties of the background on which the tractor will actually work: the physical, mechanical and technological properties of the soil and the geometry of the field surface. A tractor intended to operate in all seasons and in all weather conditions places particularly strict demands on this description, since the soil is wetter in some seasons and harder in others, and the range of conditions it must be able to meet is correspondingly wide.

Agro-technological zoning of cultivated land

The most useful official description of the conditions under which cotton is grown is found in the typical technological maps for the cultivation of agricultural crops. These maps were developed on the basis of Presidential Decree PF-5708 (2019) and Cabinet Resolution PK-307 (2022) [1]. They take into account resource-saving and innovative technologies and the achievements of science and engineering, and they aim to modernise agriculture, to extend the use of new biological and chemical means of production and to secure quality output from sowing to harvest at a lower cost. For our purposes their most important feature is that they are not uniform across the country. They are drawn up with regard to the soil-climatic conditions of individual regions, and they divide the rural districts of the Republic of Karakalpakstan and of the provinces into zones according to soil composition, the demands of agro-technological operations and the fuel and lubricant consumption on the land actually in use.

Three zones are distinguished. The first covers foothill land on which the upper layer has a noticeable slope, precipitation is comparatively high and seeds can germinate on natural soil moisture, so that no pre-sowing irrigation is needed; a considerable part of this zone has non-saline soils. The second zone is also foothill land, but with an insignificant slope and lower precipitation, so that natural moisture does not suffice for germination and a pre-sowing irrigation is required to accumulate water in the soil. The third zone consists of land with a slightly sloping surface whose soils are saline to varying degrees, and it requires leaching of salts before sowing. The characteristics are summarised in Table 1.

Table 1

Agro-technological zones of the republic according to the typical technological maps for cotton [1]

Zone	Surface and slope	Moisture conditions	Soil salinity	Pre-sowing requirement	Territories included
I	Foothill land, noticeable slope of the upper layer	Relatively high precipitation; seeds germinate on natural moisture	Largely non-saline	None in terms of irrigation	Fergana Valley provinces, Kashkadarya, Samarkand, Surkhandarya, Jizzakh, Namangan, Tashkent

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II	Foothill land, insignificant slope	Low precipitation; natural moisture insufficient	Not specified in the source	Pre-sowing irrigation to accumulate moisture	Most districts of Fergana; parts of Andijan, Surkhandarya, Namangan, Navoi, Jizzakh, Kashkadarya, Samarkand
III	Slightly sloping surface	Not specified in the source	Saline to varying degrees	Leaching of salts before sowing	All districts of Karakalpakstan, Khorezm, Syrdarya and Bukhara; parts of Andijan, Tashkent, Jizzakh, Samarkand, Navoi, Surkhandarya, Kashkadarya

Two observations about this classification matter for machine design. The first is that the zones are defined by the combination of slope, moisture and salinity, and each of these affects the tractor differently. Slope influences stability and the lateral forces on the wheels. Moisture governs the load-bearing capacity of the soil and the days on which the field can be entered at all. Salinity does not act on the running gear directly, but it dictates the operations that precede sowing, notably leaching, and therefore the condition of the surface and of the soil at the time when machines must enter the field. The second observation is that the assignment of a district to a zone is, by the authors' own admission, conventional. Within a single district one may find soils typical of different zones, and for this reason the zones should be read as tendencies rather than sharp boundaries.

It is also worth noting what the zoning does not say. The technology of cotton cultivation differs between zones mainly in the agro-technological measures used to prepare the land for sowing; the later operations are broadly similar. A tractor that is to be universal must therefore be capable of working on all three zones during the long sequence of operations that follows sowing, while the pre-sowing period is where the zonal differences are greatest and where the requirements on the chassis are most diverse.

Geographic zones of the territory

The zoning of cultivated land is complemented by a broader physical-geographic view. According to the research on which we rely [2], the territory of the republic lies within two types of geographic zone, and within each of them the climate, the structure of the relief, the vegetation and the distribution of soils are interrelated. The first zone, which occupies 71.7 % of the total area, consists mainly of lowlands with an arid climate. The second, which occupies 28.3 %, is formed by foothills and mountains with a more humid climate (Table 2).

Table 2

Geographic zones of Uzbekistan [2]

Geographic zone	Share of national territory, %	Relief	Climate
First	71.7	Mainly lowlands	Arid
Second	28.3	Foothills and mountains	Humid

The two classifications describe the same country from different angles, and they largely coincide. The foothill and mountain-edge lands in which the agro-technological zones 1 and 2 are found belong to the second geographic zone, while the lowland oases of the lower Amu Darya and the Zarafshan basin, where salinity is the controlling factor, belong to the first. For the designer this has a practical consequence. The tractor will work on very different surfaces, from gently inclined foothill fields with relatively abundant natural moisture to flat, saline lowland fields that are irrigated and leached, and the range of soil states it will meet within a single year is wide.

The arid climate of the larger part of the territory has a further effect that is often underestimated. Where natural precipitation is low, the moisture of the field is largely controlled

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by irrigation, and the timing of field operations is tied to irrigation schedules. A machine that can only enter the field in a narrow window after irrigation, or that damages the soil if it enters outside it, imposes a constraint on the whole technology. A chassis that distributes load more favourably and adapts its geometry to the moisture state of the soil can widen that window.

Selection of regions for laboratory-field research

The laboratory-field research that supports the design of the chassis could not be carried out everywhere, and the choice of sites therefore had to be justified. Three criteria were applied: the soil composition [2-6], the climatic conditions and the area under cotton. Taking these into account we selected farms located in five provinces: Khorezm (from the Lower Amu Darya natural okrug), Bukhara (from the Kyzylkum and Zarafshan okrugs), Kashkadarya (from the Kashkadarya okrug), Tashkent (from the Chirchik-Akhangaran okrug) and Namangan (from the Fergana okrug). Figure 1 shows the territories of the selected farms.

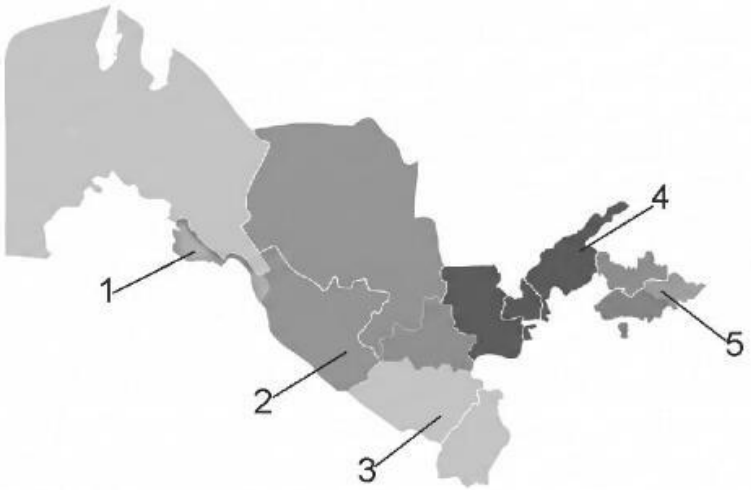


Figure 1. Map of the territories of the farms selected for the experimental work

The resulting sample is deliberately varied. When the five provinces are compared with the zoning in Table 1, a pattern appears (Table 3). Khorezm and Bukhara lie entirely in the third zone, where the soils are saline and require leaching. Kashkadarya contains land of all three zones. Tashkent combines the first and the third, and Namangan the first and the second. In other words, the sample covers the saline lowland end of the range, the foothill end with natural moisture and its slopes, and the transitional conditions between them.

Table 3

Selected regions and the agro-technological zones represented in them

Province	Natural okrug	Agro-technological zones represented (Table 1)	Dominant condition
Khorezm	Lower Amu Darya	3	Saline, slightly sloping land requiring leaching
Bukhara	Kyzylkum and Zarafshan	3	Saline, slightly sloping land requiring leaching
Kashkadarya	Kashkadarya	1, 2, 3 (parts)	Mixed foothill and lowland conditions
Tashkent	Chirchik-Akhangaran	1, 3 (parts)	Sloping foothill land alongside saline areas

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Namangan	Fergana	1, 2 (parts)	Foothill land with slope and, in places, pre-sowing irrigation

The logic of the choice is therefore not statistical representativeness in the strict sense, because five regions cannot represent a country, but coverage of contrast. If a chassis performs acceptably at the extremes of the conditions found in these regions, there is reason to expect that it will also do so in the intermediate ones. This reasoning also explains why the research programme does not treat any one region as typical: the differences between regions are the object of study, not noise to be averaged out.

Field properties relevant to running-gear design

In the fields prepared for sowing we studied four groups of indicators: the surface relief, the moisture of the soil, its hardness and its density. The reasons for selecting them are practical. Each one affects an aspect of the tractor's performance that the transformable chassis is meant to improve, and each can be measured with reasonable effort in a field setting. The methods are described separately in the companion article and are summarised here only in terms of their meaning for the design (Table 4).

Table 4

Field properties studied and their relevance to the transformable chassis

Property	What is characterised	Relevance to the running system
Surface relief: slope	Inclination of the field surface	Lateral stability, side forces on the wheels, choice of track and wheelbase
Surface relief: irregularities	Length and height of unevenness	Dynamic loads, vibration, clearance and ground-contact conditions
Soil moisture	Water content of the layers	Bearing capacity, risk of rutting and compaction, timing of field entry
Soil hardness	Resistance to penetration	Tractive conditions, susceptibility to deformation, depth of effect
Soil density	Mass per unit volume by layer	Degree of compaction before and after machine passes

Relief deserves special mention, because it links the soil-climatic description to the geometry of the machine. The slope of the surface determines how large the lateral component of the tractor's weight will be and, together with the height of the centre of gravity and the track, how close the machine is to the limits of stability. The length and height of the irregularities define the excitation that the field transmits to the tractor as it moves, and this in turn influences vibration, the dynamic component of wheel loads and the minimum clearance that is needed to avoid contact with the surface.

Moisture, hardness and density form a related group. Moisture is the most variable of the three and the one that changes fastest in an irrigated field; hardness and density respond to it, and they are also what machine passes alter. In addition, we were interested in the way the state of the soil changes under the combined action of internal factors, such as moisture redistribution, and external ones, such as loading by a machine. For this purpose a special observation device was developed, which makes it possible to follow the deformation of soil layers over time rather than at a single instant.

From field conditions to requirements for a transformable chassis

The zonal description becomes useful for the designer only when it is converted into statements about what the chassis must be able to do. At this stage of the work we can formulate such statements only in qualitative terms, as hypotheses to be tested against the measurements, since the numerical ranges depend on the data collected in the experiments. Table 5 sets out the connections that follow from the zonal description.

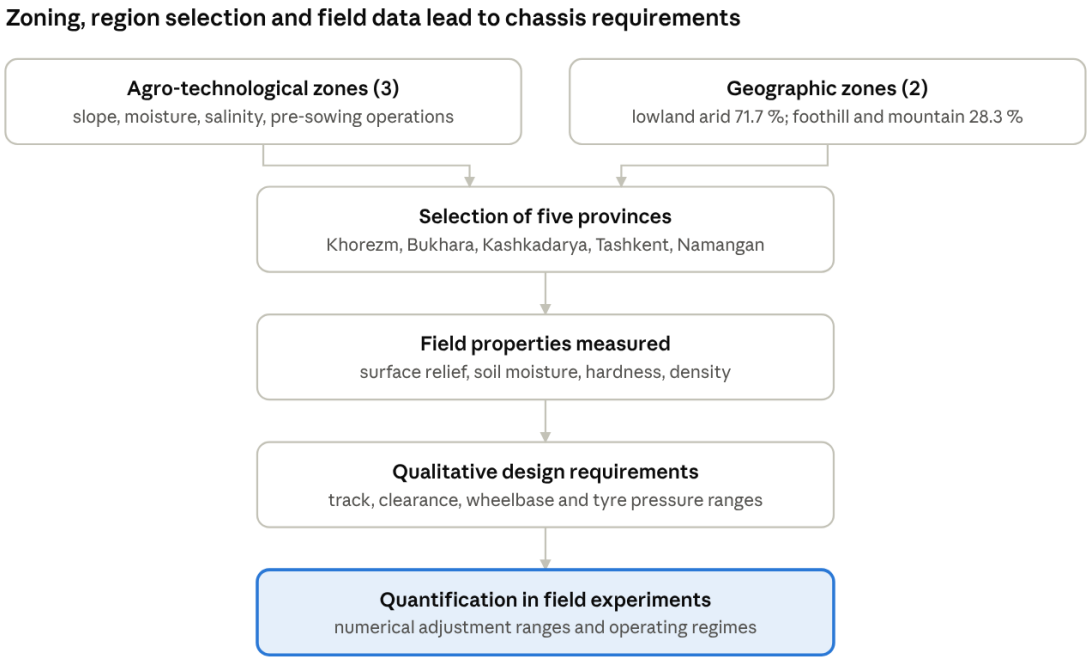
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Table 5

Qualitative design implications of the zonal conditions (hypotheses to be verified by measurement)

Zonal condition	Consequence for operation	Implication for the transformable chassis
Noticeable slope (zone 1)	Greater lateral load, reduced stability	Adjustable track and wheelbase to lower the risk of overturning and slipping sideways
Natural moisture sufficient (zone 1)	Earlier field entry, variable soil state over the season	Geometry and tyre pressure adaptable to changing soil state
Pre-sowing irrigation needed (zone 2)	Operations tied to the period after watering	Wider range of soil conditions at field entry, favouring low-pressure configurations
Saline soils and leaching (zone 3)	Wet surface in the pre-sowing period, risk of deep rutting	Configuration that spreads load and avoids repeated tracking of the same line
Slight slope but extensive flat fields (zone 3)	Long working runs, transport between fields	Stable transport configuration and efficient field configuration in one machine
Row-crop operations in all zones	Passage between rows without damaging plants	Adjustable clearance and track matched to row spacing and plant height

Several general requirements follow from the table. First, the adjustment range of the track should be wide enough to match the row spacing used in cotton and to provide a stable base for slope and transport work. Second, the range of clearance should cover both low-profile transport and field work over developed plants. Third, the wheelbase adjustment should be available as a means of influencing the distribution of load between axles and of changing the manoeuvring characteristics. Fourth, the system should permit tyre pressure to be adjusted so that the contact pressure can follow the soil state. Fifth, all of these configurations should be reachable without long or laborious operations, otherwise they will not be used in practice. Figure 2 summarises the logic that links the soil-climatic description to these requirements.



from soil-climatic zoning to chassis requirements · 5 stages

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Figure 2. From the soil-climatic description to the requirements for the transformable chassis

Discussion and limitations

The analysis presented here has limits that should be stated openly. The zones in the typical technological maps are conventional, so the sample of five regions cannot capture all of the variation that exists within them; the region is a coarse unit, and field-to-field differences in relief and soil may be as large as differences between regions. The qualitative implications in Table 5 are inferences from the zonal description and from engineering reasoning, and they do not replace quantitative measurements. Finally, the zoning is oriented to agro-technological operations and to fuel consumption rather than to the mechanics of the tractor, and some properties that matter for the chassis, such as the spatial variability of moisture within a field, are only indirectly reflected in it.

At the same time, the approach has a particular advantage. It begins with an officially adopted, widely used classification, so the results can be related to the terms in which agronomists and farm managers already think. It also makes the logic of the choice of experimental sites transparent: the sample was constructed to cover contrast between zones. This makes it easier to extend the work to other regions, for instance by adding a province that represents a combination of conditions not yet covered.

Conclusions:

1. The design of a universal row-crop tractor with a transformable chassis must be based on a description of the soil-climatic and agro-technological background, because the adjustment ranges of clearance, track and wheelbase are new design parameters that cannot be taken from the practice of conventional tractors.
2. The typical technological maps divide the cultivated land of the republic into three agro-technological zones that differ in slope, moisture conditions, salinity and pre-sowing operations. The assignment of districts to zones is conventional, and soils typical of different zones may occur within one district.
3. The territory of the republic belongs to two geographic zones, a lowland arid zone covering 71.7 % and a foothill and mountain zone with a humid climate covering 28.3 %, and the two classifications largely correspond.
4. Five cotton-growing provinces, Khorezm, Bukhara, Kashkadarya, Tashkent and Namangan, were selected for laboratory-field research on the basis of soil composition, climate and cotton area. Together they span all three agro-technological zones and give contrast between saline lowland and sloping foothill conditions.
5. Surface relief, soil moisture, hardness and density are the field properties most relevant to the running system, and the zonal differences translate into qualitative requirements for adjustable track, clearance and wheelbase and for adaptable tyre pressure. These requirements will be quantified in the experimental programme described in the companion article.

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