On the Development of Agricultural Mechanisation to Ensure a Long-Term World Food Supply [1]

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1. Foreword

According to a recent study [1], "at the present time sufficient food is produced globally to feed the current population (6.1 billion). The fact that nearly 800 million people nevertheless go hungry is a problem of distribution rather than one of a technological nature". This mainly affects the following areas: Sub-Saharan Africa, where production is at a standstill; the former Soviet Union and some Eastern Block countries, where the breakdown of the socialist economy has had a negative effect on food supplies to the population; a few other Latin American and south-east Asian countries, particularly North Korea.

However, the forecasts in the rates of food production for the next 25 years (with the population increasing to a total of almost 8 billion inhabitants and the continuing use of currently available specific technologies in the various areas) show a global food production capable of feeding more than 12 billion people. In practice, this means that there will be surpluses in North America, Europe, Japan, China and India, while there will be a food shortage in Latin America and on the African continent in particular. Hence, there is no doubt that parallel to the development of agriculture in poor areas, *it is necessary to create a functional, reliable distribution system operating independently so that the food reaches the populations for whom it is destined*. And this also because there is no guarantee [2] that industrialized countries will continue to produce at the hypothesized levels, therefore one cannot think of resolving the problem through the aforementioned organization of a good trading system. The situation, is then serious, even in relation to environmental problems within the various areas, and to the fact that the hungriest populations lend limited consideration to such problems, which is understandable. Lastly, it must be remembered that current agricultural production has an annual average growth of 1.8%, as compared to the 3% in the '60s and, therefore, at a lesser pace than the demographic growth. Also, the World Bank has shown that in Sub-Saharan Africa the annual food increase needs to reach 4%, i.e. more than double the current figure. This can be reached through a significant progress in breeding that plays a key role in the development of the agricultural sector as well as a significant impact on the appropriate farmer mechanization.

In the face of this complex situation we must ask what role the "mechanisation system" has to play and how it has to be developed so as to be able to contribute to solving the problem. Obviously, this very much depends on: internal and international political conditions; the degree of cultural and social development of individual populations; the overcoming of firmly established agricultural traditions, and also on local pedoclimatic conditions.

2. Location factors

[1] Report presented to the "*Club of Bologna Meeting*", November 2001

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2.1. The division of countries

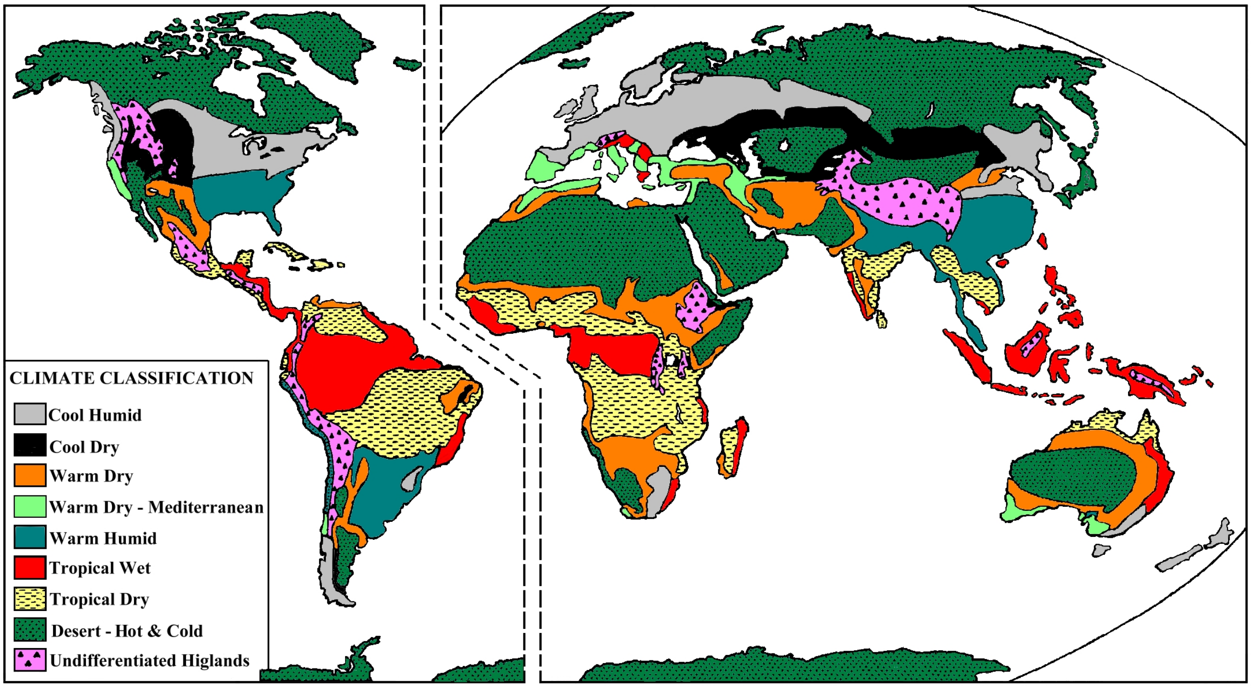
All this justifies a short analysis of the various aspects of the agricultural situations of the world' different areas based on a subdivision of the various nations into 9 main **groups** [3], as follows:

.GROUP	REGION
I	Industrialized countries with an average farm sizes over 100 ha of Agricultural Used Area (AUA): Canada, USA, Australia, New Zealand, and South Africa
II **(II[a])** **(II[b])**	Industrialized countries based on small farms Japan Western Europe, Palestine and Israel
III	Central and Eastern Europe
IV	Russian Federation (Eurasian country)
V	Former Asian Soviet Republics
VI	South and East Asia and Pacific islands
VII	Near East and North Africa
VIII	Sub-Saharan Africa
IX	Latin America

2.2. Climatic conditions

The division of countries into groups is not fully convergent with climatic areas of the world (**Fig. 1**). Some groups include countries of different continents; this is the case of **group I**, in which North America has cold climates with wet winters and the average temperature of the warmest month is below 20^{o}C in Canada and Alaska and above this figure in the north and mid-west of the USA. In northern parts of Canada and Alaska the tundra climate prevails. On the other hand, in the south-east of the USA, along some parts of Pacific coast of the USA and Canada, in the south-east of Australia and New Zealand wet, temperate climates prevail and the average temperature of the warmest month is above 20^{o}C. Most of Australia's territory consists of dry desert and steppes with periodically dry savanna climates. Warm, temperate climates with dry winters prevail in South Africa.

Figure 1 – World map of agricultural climate classification [Source: 3]



The dominant climate in **group II** is damp and moderate with wet winters and the average temperature of the warmest month is below 20°C. A warm climate with an average temperature of the warmest month above 20°C prevails in the Mediterranean zone. However, in Scandinavia, as well as in a large part of central and eastern Europe, there are cold climates with wet winters; in southern parts of the Ukraine a steppe climate with dry summers and cold winters prevails. Cold climates with wet winters are typical of most of the Russian Federation; cold climates with dry winters prevail in eastern Siberia, and tundra climates in northern Siberia.

In some southern regions of the Russian Federation there is continental steppe climate with cold winters and hot summers.

In **group V** countries desert and steppe climates are typical. Warm, temperate, rainy climates with the driest season during winter are typical of **group VI**.

However, the climatic zones in this group of countries are differentiated, with a tundra climate in the Himalayas, Karakorum and the Tibetan highlands, dry desert and steppe climates in western parts of China and Mongolia, cold climates with dry winters prevailing in northern China and North Korea. Hot, humid rainforest and periodically dry savanna climates prevail in Malaysia, Indonesia, the Philippines and in most territories of the Oceanic islands. Desert and steppe climates are more widespread in **group VII**. Only terrains near the Mediterranean Sea and Atlantic Ocean, as well as along the Euphrates and Tiger rivers, have a warm, temperate climate with long, hot, dry summers and an average temperature of the warmest month above 20°C.

Hot, humid rainforest and periodically dry savanna climates dominate in **group VIII**; however, there are also: large areas with steppe and desert climates in the north and in the south-west of the region; a warm, temperate climate with long, hot, dry summers and an average temperature of the warmest month above 20°C in the southern part of the continent and in Ethiopia. **Group IX** has hot, humid rainforest and periodically dry savanna climates, but there are also steppe and desert areas, as well as some with warm, temperate climates, with moderate precipitation in all months (southern Brazil, Uruguay, north-east Argentina, southern Chile, some parts of Mexico).

2.3. Soil and vegetation conditions

Soils (**Fig. 2**) and vegetation (**Fig. 3**) distribution is correlated with climates. In Asia and in Eastern Europe soils are evenly distributed across a parallel of latitude.
Red soils occupy the largest area on the Earth. Present in equatorial and tropical zones, they are typical of hot climates. Grey desert-soils are typical of desert areas of all the continents.
Podzols occupy large areas in northern parts of Eurasia and North America, while brown soils feature in Western Europe, North America and Eastern Asia. The best mould (humus) soils prevail in the steppe and savanna climates of Eurasia, North and South America, Africa and Australia. Climate and the configuration of terrain determine soil erosion.
Water erosion is more of a danger in uncovered, hilly terrains with high levels of precipitation. Wind erosion prevails in areas with dry climates and lack of plant cover makes it more likely and dangerous. *Soil degradation is a serious problem*. One of the causes is inappropriate farming methods (implying also inappropriate mechanisation).
Here the main types of degradation are bio-chemical (loss of soil fertility) and physical (loss of soil structure). In irrigated areas 10 to 15% of fields suffer from salt contamination [1].
According to FAO data *1,214 million ha have been degraded; in this, water erosion contributed 61.6%, wind erosion 23.1%, chemical degradation 12.1% and physical degradation 3.2%* (**Fig. 4**).

Figure 2 - World map of types of vegetation [Source: 3]

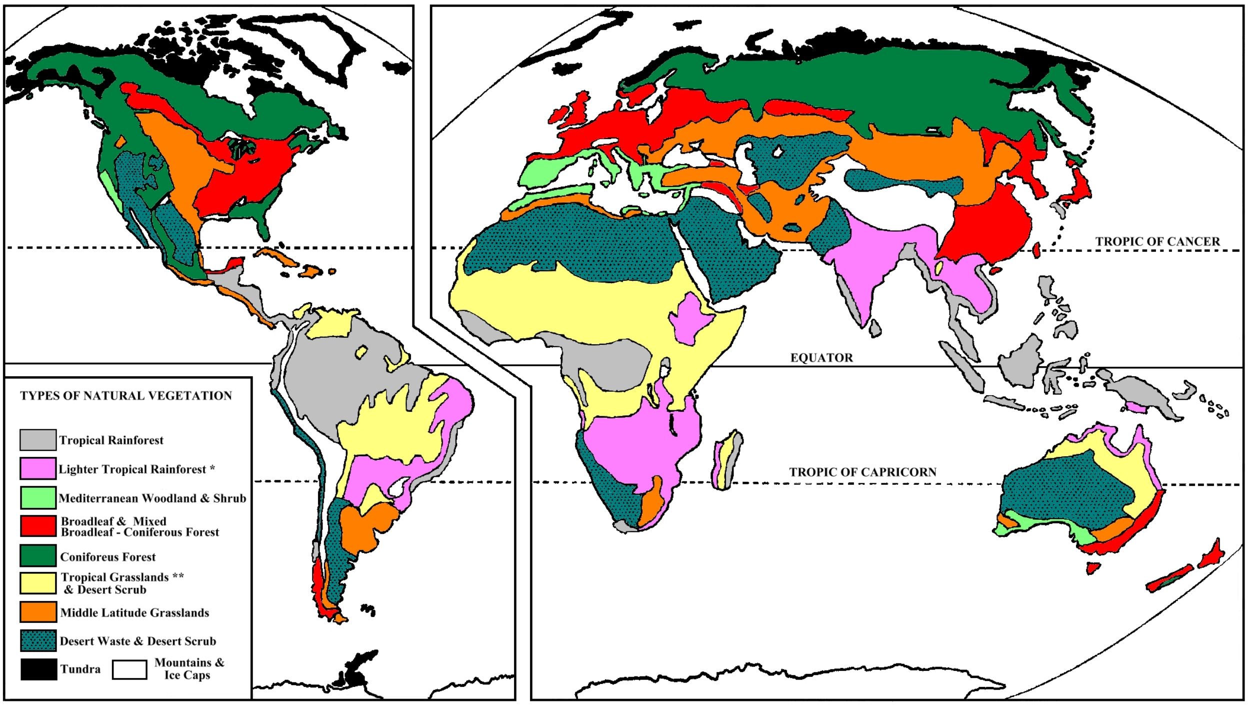


Figure 3 - World map of categories of soil types [*Source:* 3]

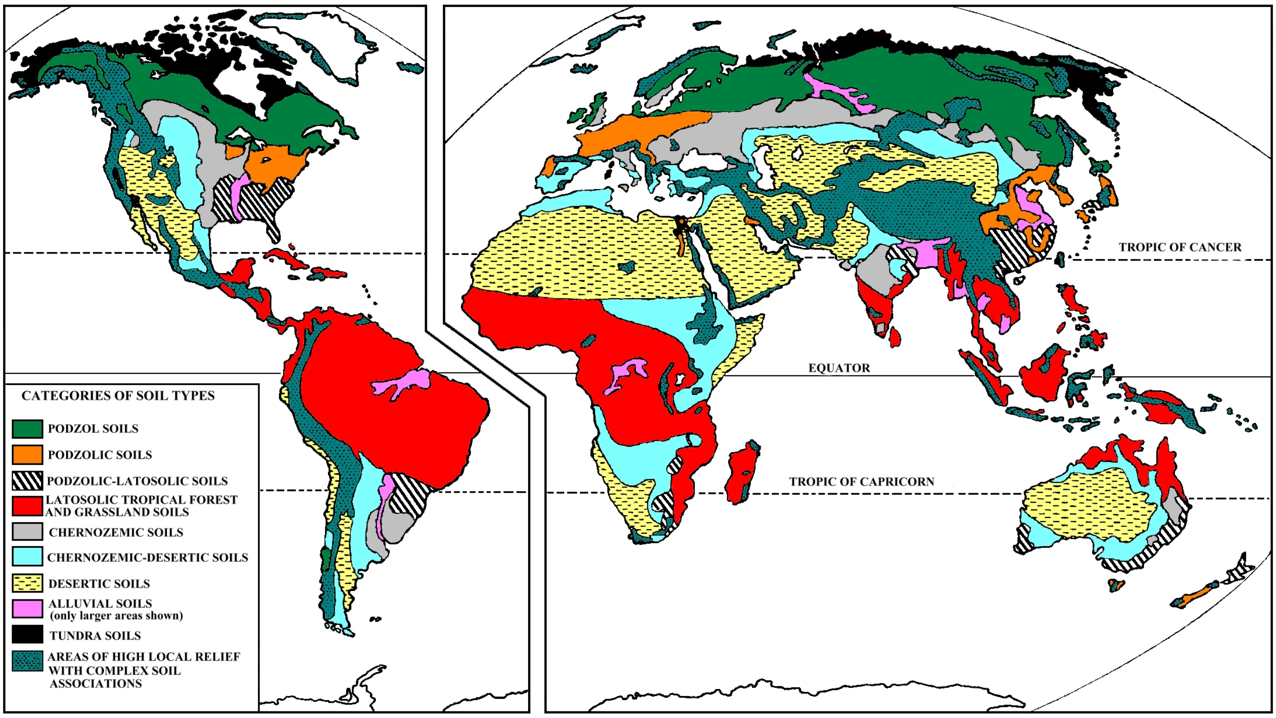
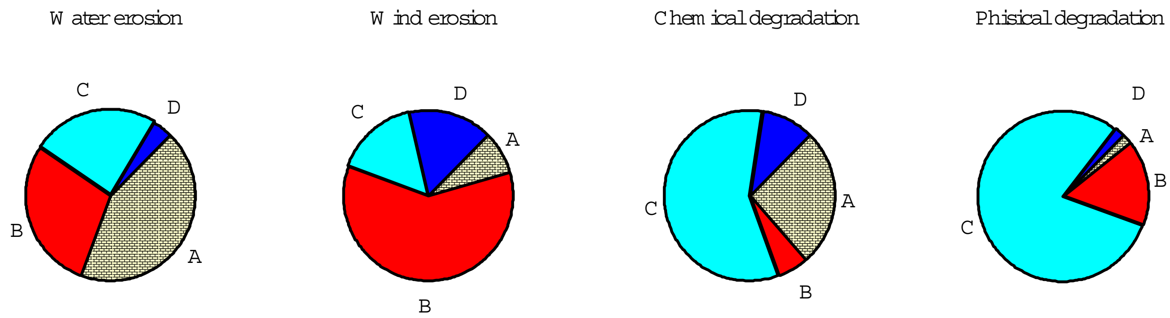


Figure 4 - Land degradation according to cause



A – Deforestation; B – Overgrazing; C - Unsuitable cultivation practices; D - Other

3. Conditions for development

3.1. Production systems

On the basis of the aforementioned conditions there are, obviously, different farming systems which, [4], fall into four main categories:

i) *plantation perennial*;
ii) *tillage*;
iii) *alternating*;
iv) *grassland and grazing*.

For each of them the production techniques used are different and four different levels of mechanisation emerge:

i) *hand tools*;
ii) *draught animal power*;
iii) *simple motor mechanization*;
iv) *sophisticated technology*.

The first two levels are peculiar to Africa (with the exception of South Africa); the first three are found in various countries throughout South America and South-East Asia; lastly, the fourth is characteristic of the countries in **groups I** and **II** [5]. *This is clearly correlated with the salary levels in the different areas.* In any case [4] a biologically efficient production system which, in temperate areas, has to supply approximately 1,000 Mcal per person per year, must:

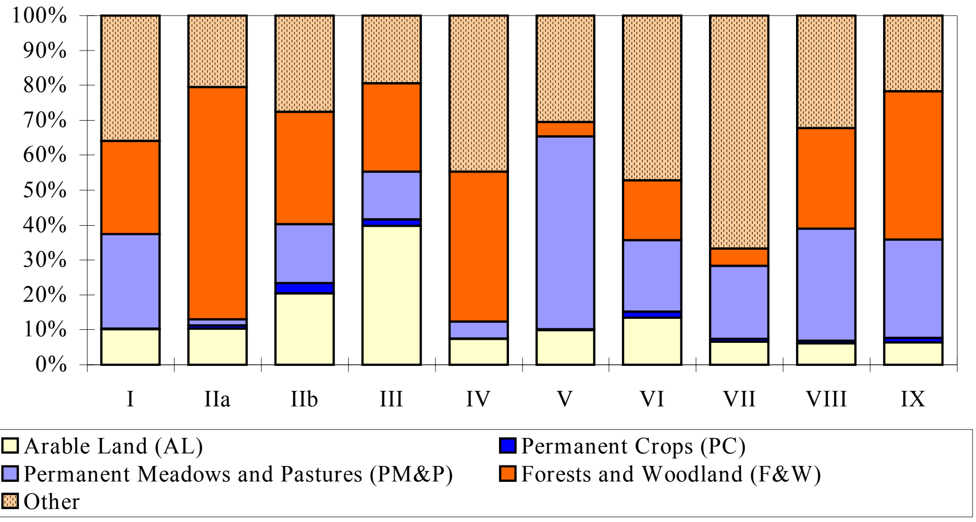
- provide adequate storage and distribution facilities, given that the climate, and hence production, is highly seasonal;
- provide, with minimum "off the farm" wastage, the processing methods, equipment and cooking needed to reduce crops and animal products digestible by and attractive to man;
- maximize plant growth and minimize "on farm" plant and animal wastage;
- achieve the above by applying the more appropriate input ratios of energy in skill labour, animal work, mechanical work and scientific and industrial inputs;
- be reliable between and within years, months and weeks;
- be consistent over decades;
- be capable of reduction, expansion or adjustment (production flexibility) to meet changes in population or in demand.

It seems then necessary to: minimize both farm stock losses and "off the farm" processing losses; maximize output with adequate agricultural practices and therefore, suitable mechanisation, optimising energy costs; develop flexible agricultural production to adapt to the market demand.
A farmer's choice of a production system [6] is governed by physical constraints relating to farm resources (e.g.: soil quality), as well as climate influences, financial considerations, and in increasingly, environmental standards. All this involves a decision making process very much influenced by the farmer's knowledge, awareness, skills and aspiration. There is consequently the need to support any initiative for the development of specific educational programmes all over the world. This means an increasing importance of knowledge, so to assume appropriate decisions, and a reduction of the intensity of equipment and energy. The general trend is in fact in favour, also in agriculture, of a progressive dematerialisation [7].

3.2. Use of land [5]

There are significant differences in the use of land between regions (**Fig. 5**).

Figure 5 - Land use in different regions of the world



In Japan and on the islands of Oceania forests dominate. However in Eastern and Central Europe, the AUA amounts to more than 50% of the land; the predominant share of AUA is observed also in former Asian Soviet Republics. However, in this region this is due to the high share of PP with a very low share of F&W. In particular groups of states the share of different kinds of AUA as compared to the total area varies greatly, particularly:

- in **group VII**: the share of AUA varies from 3.3% (Egypt) to 72% (Syria); AL from 0.1% (Oman) to 34.3% (Turkey); PC from 0.01% (Mauritania) to 12.3% (Lebanon) and PP permanent pastures from 0% (Egypt) to 42.2% (Syria);
- in **group I** the share of AUA varies from 7.4% (Canada) to 77.4% (South Africa), AL from 4.6% (Canada) to 18.9% (USA), PC from 0.01% (Canada) to 6.4% (New Zealand) and PP from 2.8% (Canada) to 64.1% (South Africa).

On average, about 36% of the world's land are used for agricultural purposes. The climatic conditions make it impossible to use some areas for crop production (tundra, deserts). With

[5] **AUA**: Agricultural Used Area; **AL**: Arable Land; **PC**: Permanent Crops; **PP**: Permanent Pastures; **F&W**: Forest and Woodland; **PM&P**: Permanent Meadows and Pastures

irrigation it is possible to enlarge agricultural areas, if water sources are available. The large-scale use of the waters of the Syr Daria and Amu Daria rivers for irrigation purposes in former Soviet Central Asia caused a serious lowering of the water level in the Aral Sea.
Irrigation can also lead to salinity of the soils irrigated. From here, the need to use appropriate irrigation systems, probably based on the drip solution.
The transformation of forest areas into agricultural ones would be very dangerous, causing negative changes in climate and in the natural environment in general. Therefore, *increasing the AUA cannot be considered as a method for ensuring a food supply for the world's increasing population.*
PM&P dominate in most regions, where agricultural production is rather of extensive nature. In Japan and Europe, on the other hand, AL and PC amount to more than 50% (**Fig. 6**).
The lowest AUA per inhabitant is found in Japan (this is the case of all categories of the area) and the highest one in former Soviet Asian republics where, however, PP have the dominant share in the AUA. Instead, the highest area of AL per inhabitant exists in the Russian Federation (**Table 1**).

Figure 6 - Surface and structure of the AUA in different regions of the world

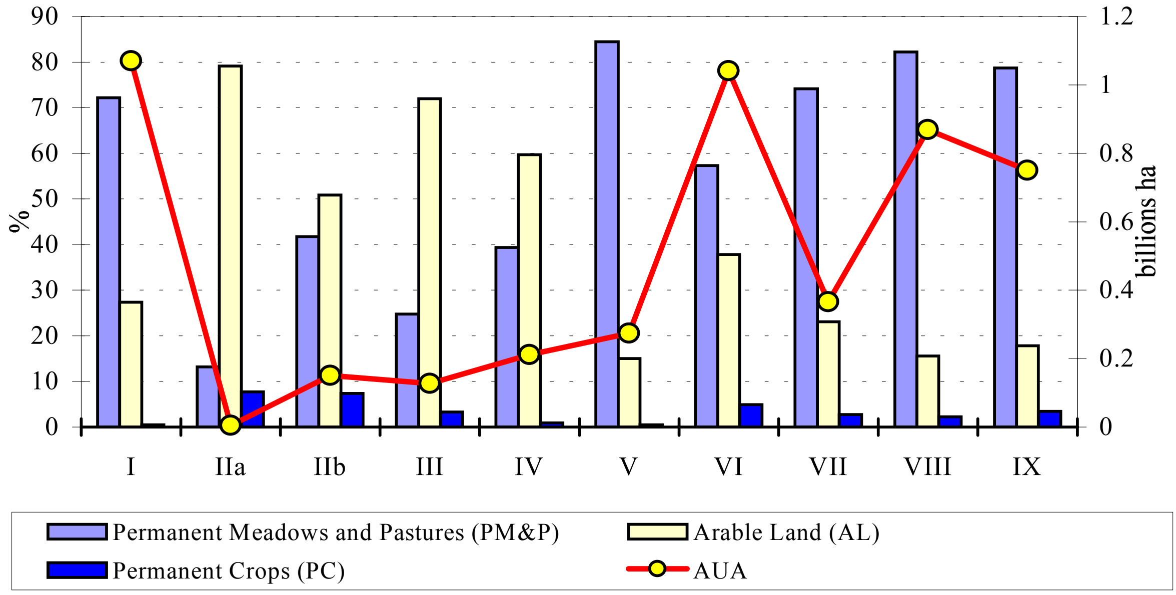


Table 1 - Resources of Agricultural Used Area (AUA) according to region [*Source: Calculations based on 8*]

GROUP	AUA PER INHABITANT (ha)				IRRIGATED AREA	
	Total	AL	PC	PM&P	AUA, %	AL %
I	2.920	0.798	0.014	2.108	2.5	9.0
II [a]	0.039	0.031	0.003	0.005	54.6	69.0

II [b]	0.390	0.198	0.029	0.163	9.6	18.9
III	0,656	0,472	0,022	0,162	4.0	5,6
IV	1.432	0.855	0.013	0.564	2.4	4.0
V	3.849	0.579	0.020	3.251	4.5	29.7
VI	0.330	0.124	0.016	0.190	13.5	35.8
VII	0.994	0.230	0.028	0.737	6.8	29.3
VIII	1.527	0.238	0.034	1.255	0.6	3.7
IX	1.490	0.266	0.052	1.172	2.4	13.7

The AUA per inhabitant has a decreasing tendency due to the increase in population and the losses of AUA through population settlement, industrial development, infrastructures etc.
Also in the future, the resources of the AUA will decrease. According to FAO forecasts, in Third World countries (excluding China) a further 20 million ha of land with agricultural potential will be taken out of use because of other destinations or degradations.
Together with the immediate degradation of soils, the question of water must be seen as becoming more and more critical, particularly when linked with soil compaction and erosion. In many regions today the loss of water is as serious as the loss of soil [1].

3.3. Structure of farms by size
The average size of farms differs very much from one country group to another, from very small (Japan and Central, South, East and South-East Asia) to very large like in Russian Federation (**Table 2**).
The farm size is correlated with the number of people engaged in agricultural production. Generally speaking, the smaller the average size of the farm, the greater the number of people working (full- or part-time) in agriculture.

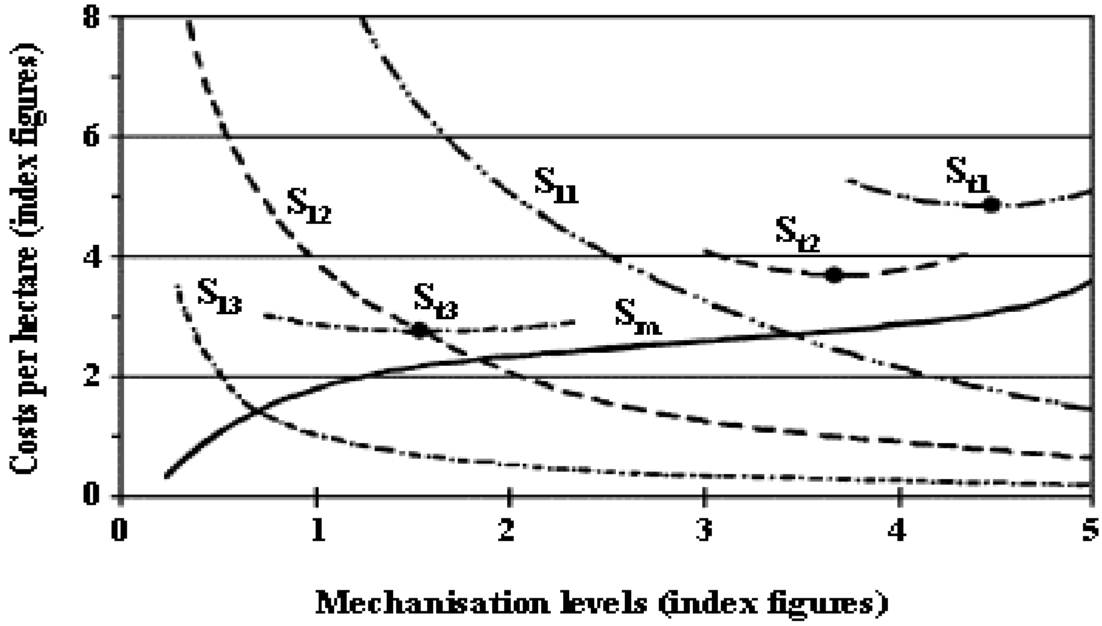
Table 2 - Average size of farms [Sources: *Calculations based on 10; 11;12;13 as well as Authors' estimations*]

GROUP	FARM SIZE (ha)				% OF FARMS	
	AL	PC	PP	Total AUA	≤ 5 ha	> 5 ha
I [1]	85.5	1.0	116.5	203.0	3.0	97.0
II [a]	1.2	0.1	0.2	1.5	97.0	3.0
II [b]	9.8	1.1	6.1	17.1	53.1	46.9
III	9.1	0.7	2.4	12.2	49.5	50.5
IV	413.7	6.1	255.1	674.8	20.6	79.4
V	143.9	4.9	808.6	957.4	20.0	80.0
VI	1.2	0.2	0.4	1.8	97.9	2.1
VII	1.9	0.2	3.4	5.5	79.0	21.0
VIII	3.2	0.5	16.7	20.3	38.0	62.0
IX	17.1	5.0	67.5	89.6	39.0	61.0

(I[1]) USA

4. Mechanisation
4.1 General problems
An appropriate mechanisation must therefore take into account all the above mentioned requisites, which are fundamental and specific to each area, and must be based on groups of machines and systems to be used efficiently and profitably, hence with productivity correlated to labour costs according to [14] basic, well-known principles (**Fig. 7**).

Figure 7 – Correlation between mechanisation levels and costs per hectare of the machines (S_m) and abour (S_l). With the increasing of wages it becomes necessary to use higher mechanisation levels able to assure higher work productivity. [*Source*: 14]



In any case, it must not be limited to field equipment, but *has also to include post-harvest technology*, with a particular focus on the storage of the produce. This means that developing countries must focus on the work options offered by machinery without allowing themselves to be blinded by inappropriate means available on the market, and they must pay particular attention to options which minimize energy and agro-chemical inputs, thus enabling them to safeguard the environment while trying to increase yields.

At the same time they must also consider [1] that: in very broad terms a farmer relying solely on his own labour can feed himself and another 3 persons, using draught animal power he can feed 6 people and using tractors he can feed up to 50 or more persons.

Figure 8 shows a graph [4], which highlights the relationship between "soil factors and farming systems". Lastly, it must be remembered that inputs – even mechanical ones – can be grouped into categories according to their intensity. Rich countries have intensely cultivated high yield areas and use sophisticated technologies that focus on ecological management while ensuring excellent cultivation flexibility at the same time. On the other hand, in poorly developed areas with a low population the conditions are the opposite. In any case [5; 15] it is necessary *to create a network of activities (institutional and/or private)* (**Fig. 9**) *aimed at contributing to the progress of agricultural mechanisation*.

Therefore, for the fruitful development of agricultural mechanisation, all involved groups from donor countries as well as from the developing ones and, last but not least, the target group, together should aim at the production of demand-oriented quantity and quality of food, fodder and commercial/industrial agricultural products and energy plants under the following conditions:

- to save resources and energy;
- to protect the environment;
- to maintain soil productivity;
- to satisfy social-cultural, economic and political aspects.

Consequently, any farming enterprise requires [6] a multilateral management capable of addressing numerous issues more or less simultaneously. Once again, there is a big problem of developing educational programmes.

In addition, [16], it is a must to take into consideration that the formulation of the world trend system and the *Information Technology* (I.T.) revolution have changed the external environment of agricultural development for all countries.

In fact, the information and knowledge-based is creating new opportunities to accelerate the transformations of traditional farming into modern agriculture. Therefore, it is necessary to learn the new trends of modern I.T. for agriculture in the developed world and to investigate appropriate ways of promotions of new technologies applications in developing countries, starting from the more advanced ones.

These have the potential to act as incubators for new ideas and sophisticated technologies based on their domestic conditions. Within this framework, it is stated that *precision farming practice may be seen as a support for cost reduction and environment protection in any country for tomorrow* [17].

One additional point to be considered is the role that *contracting companies* can play from the technical and economic view points. Their activities [9] require specific types of tractors and implements, more sophisticated and with higher working capacities.

Figure 8 – Relation between soil factors and farming systems [*Source:* 4]

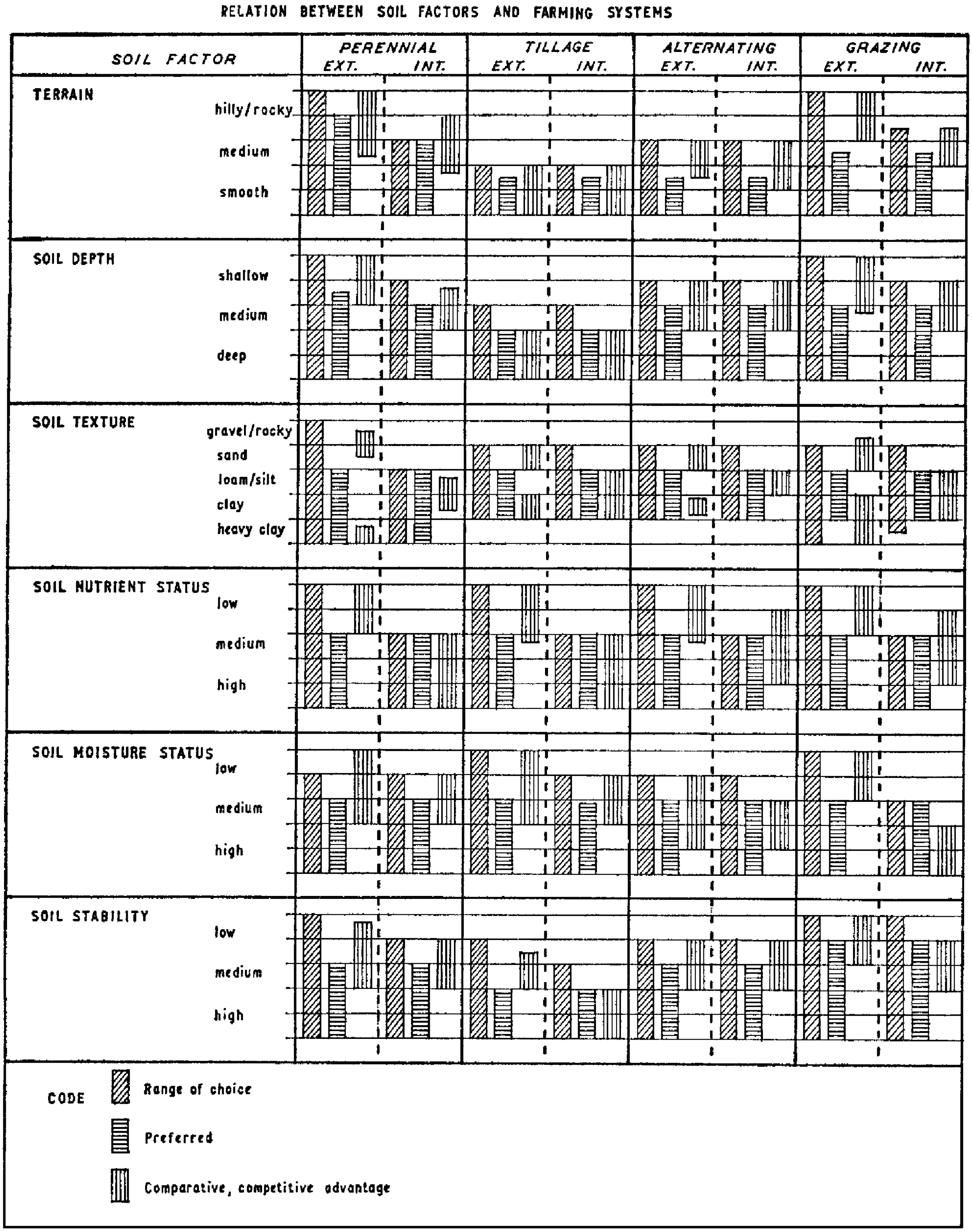
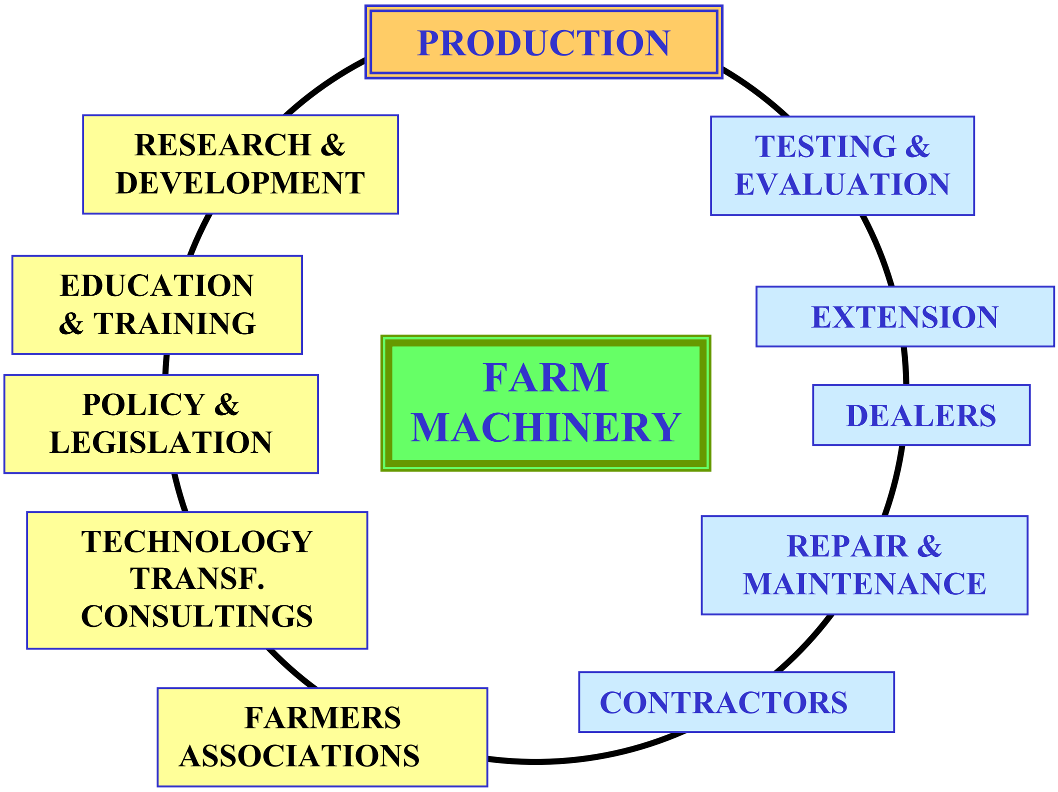


Fig. 8 Relation between Soil Factors and Farming Systems. *Source: Duckham A.N. et Al. 1970*

Figure 9 - Network of activities and institutions to be installed in each country/region in order to contribute to an appropriate choice and utilization of agricultural equipment.



4.2. Labour force in agriculture

The share of agriculture in employment of the labour force depends on the level of economic development of a country. In many developing countries, up to 80% of farm power in agriculture comes from humans. In Sub-Saharan Africa and in the Far East people working in agriculture account for more than 60% of the total EAP[6] of countries (**Table 3**).

Table 3 - Population [*Source: Calculations based on 8; 10 and 18*]

GROUP	Total Population	ECONOMICALLY ACTIVE POPULATION (EAP)						Average salary
		Total	of that in					
			Industry	Other	Agriculture			
						per 100 ha AUA	per 100 ha AL+PC	
	(10^6 persons)	(10^6 persons)	%	%	%			US$/month
I	366.3	183.7	17.2	79.8	3.0	0.54	1.95	2100
II a	125.6	65.1	21.9	72.8	5.3	62.18	71.67	2600
II b	393.1	185.0	21.5	73.5	5.0	5.25	8.93	1500
III	194.3	97.8	25.4	51.6	23.0	14.34	18.52	300
IV	148.1	85.2	35.0	51.0	14.0	4.11	6.78	120
V	71.1	31.6	9.8	64.9	25.3	2.92	18.80	140
VI	3168.5	1620.4	15.6	22.8	61.6	95.48	224.00	90
VII	361.4	132.8	19.3	48.0	32.7	11.89	46.04	110
VIII	568.9	254.8	4.9	27.9	67.2	19.71	110.73	70
IX	503.6	213.2	15.1	64.1	20.8.	5.92	27.80	600

[6] EAP: Economically Active Population

The population engaged in agriculture has decreased steadily due to urbanization; first of all this has been the case with industrialized countries. In the future the process of migration from rural areas to towns will become an increasing feature in developing countries too. Even in Sub-Saharan Africa it is estimated that the proportion of the population in rural areas will fall below 50% by the year 2025.
The EAP involved in agriculture in relation to AUA as well as to AL and PC is correlated with the level of mechanisation, the intensity of agricultural production, the size-structure of farms and the situation on the labour market. The percentage figure of EAP in agriculture per 100 ha of AUA ranges from 0.54 to 95.48.
The differences between groups of countries are slightly smaller where the area of AL and PC is taken as the point of reference. In both cases the highest indices are found in **groups VI**, **VII** and **VIII**.
In developing countries, the average salary of working people is very low, especially in Sub-Saharan Africa and the Far East. Relatively low remuneration of work is typical also for former COMECOM countries. Instead, being in industrialised countries the level of salaries very high, different mechanisation-level are necessary to assure the agricultural production economically effective and the farming at least sufficiently profitable.

4.3. Farm machines and mechanical power in agriculture
There are about 25.9 million tractors in use all over the world (0.59 tractors per 100 ha of AUA and 1.88 tractors per 100 ha of AL). The regional distribution of tractors (and other farm machinery) is very unequal; the number of tractors per 100 ha of AUA and AL as well as the number of combine-harvester per 100 ha of cereals varies from one region to another (**Table 4**).
Considerable differences exist not only between industrialized and developing countries, but also within particular groups of countries. The low number of tractors and combines in **group I**, as compared to **group II,** is due to the size of the farms. The smaller the farm is, the higher the number of machines in relation to adequate area and the smaller the number of machines per 100 farms is (**Table 5**).
The average number of tractors per 100 ha of AUA depends on the share of farms of different size in the farm structure of a country. Consequently the numbers of machines in relation to adequate areas are not a sufficient criterion to evaluate the situation of farm mechanisation in different countries. Also, the farm size structure must be taken into consideration.
Therefore, the number of tractors in **group VIII** should not be directly compared to the situation in **group I**, but rather to that of Japan, where farm structure is similar (average size of farms about 2 ha).
Also the power of tractors and self-propelled machine should be taken into consideration (**Table 6**). Lower average unitary power can be observed in Japan; it is the result of adjusting the farm machines to the structure of farms in the country.

Table 4 - Tractors and combine harvesters by region [*Source: Calculations based on 8*]

GROUP	NUMBER OF TRACTORS			NUMBER OF COMBINE HARVESTERS	
	10^3	per 100 ha AUA	per 100 ha AL	10^3	per 100 ha of cereals
I	6002.3	0.56	2.05	866.3	0.86
II [a]	2123.0	42.91	54.23	160.0	7.80
II [b]	6854.1	4.54	8.92	606.9	1,50
III	3482.1	2.73	3.80	298.3	0.73
IV	886.5	0.42	0.70	317.0	0.63
V	444.1	0.16	1.08	75.4	0.49
VI	2763.4	0.26	0,70	1250.4	0.48
VII	1585.8	0.43	1.88	50.2	0.11
VIII	161.6	0.02	0.12	5.1	0.01
IX	1587.5	0.21	1.19	159.6	0.35

Table 5 - Rate of equipment of farms in tractors (situation at 1996) [*Source: Calculations based on 19 and 20*]

SIZE FARMS	NUMBER OF TRACTORS			
	100 ha AUA		100 farms	
	Germany	Poland	Germany	Poland
1-5 ha	27.35	10.79	67.88	27.22
5-10 ha	22.14	10.51	159.33	74.92
10-20 ha	15.67	8.77	228.11	118.99
20-50 ha	9.09	6.41	288.85	174.29
> 50 ha	2.69	1.66	396.40	548.90
Average	6.87	7.45	204.47	61.79

Table 6 - Mechanical power in agriculture [*Source: Calculations based on 10 and 21*]

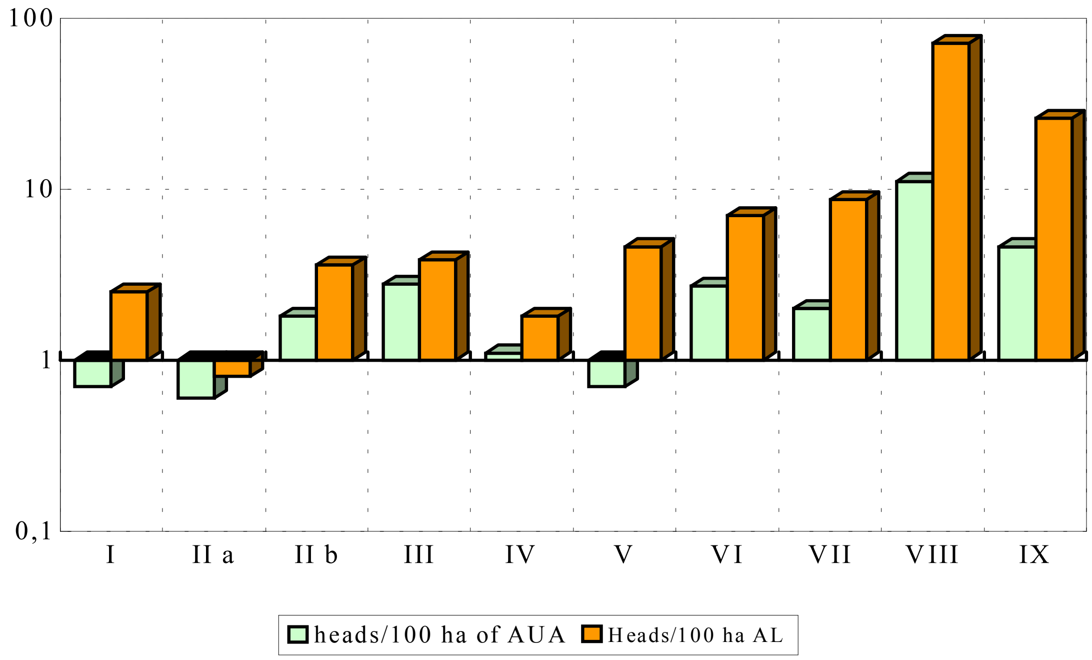
GROUP	**POWER** (kW/100 ha AUA)				**AVERAGE POWER** (kW)		
	Tractors	Walking tractors	Combine harvesters	Total	Tractors	Walking tractors	Combine harvesters
I	35.1	1.0	7.0	43.1	62.5	7.0	86.0
II [a]	918.4	121.5	39.5	1079.4	21.4	3.5	12.2
II [b]	205.7	14.7	31.6	252.0	45.3	8.8	78.5
III	106.6	1.0	18.1	125.7	39.0	4.0	77.5
IV	27.3	1.6	11.9	40.8	65.1	3.4	78.9
V	9.9	0.5	2.2	12.6	61.0	3.5	78.0
VI	8.0	14.0	3.6	25.6	30.4	8.9	29.7
VII	21.8	0.1	0.5	22.4	50.3	6.3	36.1
VIII	0.7	0.4	0.1	1.2	40.0	7.5	61.0
IX	11.6	1.5	1.8	14.9	54.9	7.3	85.4

4.4. Animal power

In developing countries working animals are still an important source of power for agricultural production. In this study only horses, mules and asses have been taken into account considering (**Fig. 10**) the number of these animals per 100 ha of AUA and per 100 ha of AL.

Working animals are competitive with the human population as "users" of potentially convenient areas for food production. It is a paradox that animal power mostly exists in countries with a food shortage and not in the ones with an overproduction of food. In industrialized countries some experts are calling for a return to animal power in countries with a food surplus. They argue that the use of horses as a source of power would be favourable to the environment and could help to reduce the consumption of fossil fuels.

Figure 10 - Working animals in relation to Agricultural Used Area (AUA) and to Arable Land (AL)



5. Inputs in agriculture

In **groups I**, **II**[a] and **II**[b] field operations are fully mechanised; however, number of hours worked by tractors and combines-harvesters (**Table 7**) are strongly diversified.

Table 7 – Work inputs and annual use of machines [*Source: Calculations based on 10 and Authors' estimations*]

GROUP	**LABOUR** (h/100 ha AL)			**ANNUAL USE** (h)		
	Tractors	Walking tractors	Combines	Tractor	Walking tractor	Combines
I	2002	3	65	975	55	220
II [a]	3796	154	123	70	35	30
II [b]	3150	25	101	353	75	155
III	2345	3	61	617	75	188
IV	844	3	70	1200	40	280
V	1295	4	55	1200	40	300
VI	353	236	95	503	566	300
VII	2258	3	20	1201	394	340
VIII	142	19	1	1200	550	400
IX	1424	60	49	1200	520	410

The inputs of work hours per 100 ha of AL depend not only from the level of mechanisation, but also from working capacities of machines in use, from working conditions (size of fields) and intensity of agricultural production. Therefore, in Japan, where the power of tractors and combine-harvesters is the lowest, the fields are very small and the level of production per unit of agricultural used area is high, the inputs are significantly higher as compared to **group I**. In the case of combine-harvesters, the inputs depend also on the share of cereals in the AUA.

The lowest inputs of number of hours worked by tractors and combines-harvesters per 100 ha of AL have been observed in **group VIII** where the level of mechanisation is very low. There is not a correlation between the annual use of tractors and combine-harvesters and the number of hours worked by these equipment per 100 ha of AL. The annual use depends on scale of production and, generally, it is higher on larger farms. It also depends on number of machines per unit of surface of adequate area and on form of utilisation; in cases of multi-farm use it is higher as compared to the individual use system. Therefore, in Japan, where farms are small and the rate of equipment of agriculture in tractors and combine-harvesters relatively high, the annual use is low. In other situation, generally in developing countries, the use of tractors "off the farm" is usual and this gives us non correct figures.

Inputs of energy per unit of AUA depend on level of motorization, per cent share of AL and PP in the AUA, intensity of agricultural production and natural conditions (climate, soils etc.). In Japan, intensive agricultural production and high share of AL and PP resulted in highest value of energy inputs; at the same time, the value of index of energy inputs per unit of agricultural production is the lowest one (**Table 8**).

In Japan, the relatively low energy inputs per unit of production has been achieved under conditions of a very high use of commercial fertilisers (**Table 9)**. The use of agro-chemicals per unit of AUA differs very strongly from a region to another. In Sub-Saharan Africa, inputs of N-P-K in commercial fertilisers are about 200 times lower than that of Japan; this is one of the reasons of low level yields in Africa.

Table 8 - Energy spent in agriculture and prices [*Source: Calculations based on 10; 22; 23 and 24 and Authors' estimations*]

GROUP	ENERGY INPUTS			ENERGY PRICE	
	% of national consumption	10^{12} J per 100 ha AUA	10^{12} J per 10^3 US$ of GAO	Diesel oil (US$/kg)	Electric energy (US$/kWh)
I	4.4	0.40	13.0	0.319	0.040
II [a]	1.0	2.86	2.6	0.840	0.150
II [b]	3.0	1.64	12.9	0.649	0.069
III	7.4	1.36	33.1	0.401	0.037
IV	6.3	0.73	49.2	0.400	0.050
V	7.0	0.25	47.0	0.400	0.050
VI	10.0	0.32	8.6	0.458	0.048
VII	28.6	0.51	19.4	0.531	0.075
VIII	*	0.02	3.4	0.500	0.075
IX	0.6	0.31	17.7	0.307	0.038

Table 9 - Agro-chemical inputs [*Source: Calculations based on 25; 26 and 27]*

GROUP	**FERTILIZERS** (kg/ha AUA)				**PESTICIDES and HERBICIDES** (kg/ha AUA)
	N	P_2O_5	K_2O	N-P-K	
I	13.4	6.2	5.4	25.0	0.3
II [a]	99.9	120.1	85.3	305.3	9.7
II [b]	65.7	24.8	28.3	118.8	4.9
III	41.0	12.8	15.7	69.2	0.5
IV	4.7	1.5	1.7	7.9	N.A.
V	2.2	0.9	0.5	3.6	N.A.
VI	41.2	15.5	6.9	63.6	N.A.
VII	9.9	4.4	0.7	15.0	N.A.
VIII	0.8	0.4	0.3	1.5	N.A.
IX	6.1	4.3	4.1	14.5	N.A.

Japan as well as Western Europe countries have also a very high consumption per ha of AUA of pesticides and herbicides; instead this consumption in **groups I** and **III** is significantly lower. The reasons for **group I** are the high share of PM&P and the extensive type of agricultural production, possible and rational there thanks to high land resources per inhabitant. In countries of **group III**, the use of agro-chemicals during the transformation period has been decreased because of rise in prices of these products and the relatively low profitability of agricultural production. In Japan, where the AUA per inhabitant is low, an intensive production system is necessary.

Labour inputs per hectare depend on level of mechanisation, production systems, working conditions (size of fields etc.) and, of course, on crop and its yield. In Japan, the inputs are significantly lower than in other industrialised countries; the reason is due to the small size of fields, hampering achievement high operation capacities of farm machines. Besides, most of farm machines in use are adjusted to existing farm size structure. Machines are small and they have rather low working capacities; their use is economically justifiable. The potential of theoretical working capacities of larger machines would not be sufficiently used on fields of small farms and the costs would be too high.
Instead, on large farms of countries included to **group I** use of high capacity machines is common. On large fields high working capacities have been achieved. Therefore, the labour inputs per hectare of particular crops are lowest in **group I**. The large size of most farms are also typical for Russian Federation and for the majority of countries of central and eastern Europe and former Asian Soviet Republics. However, the insufficient qualitative and quantitative levels of the agricultural equipment in these countries cause that the labour inputs per hectare of particular crops are, in **groups III**, **IV** and **V,** higher as compared to **group I**.
High unitary labour inputs in developing countries are a result of low mechanisation. Highest labour inputs are in Sub Saharan Africa, where the use of hand labour is still common. Labour inputs per hectare of maize-grain (yield 9 dt/ha) in a case of hand operation amount to 786 hours (women) or 725 hours (men) and in a case of using animal power, 319 hours [25].

6. Crop production

Group VI and **I** have the highest share in cultivated area of four cereals (wheat, barley, rye and oats); however, **group II**[b] are the second, following central and Southeast Asia, producer of the cereals, even though their share in area cultivated for these crops is limited (higher yields).
Central and Southeast Asia is also the greatest producer of rice, pulses and potatoes and the second, following countries of **group I**, producer of maize-grain (**Table 10)**. Latin America and Central and Southeast Asia are main producers of sugar-cane while Western Europe is the main producer of sugar-beets.
Yields are, in general, positively correlated with the use of agro-chemicals as well as the intensity of mechanisation.

7. Animal production

In central, south and east Asia there are more than 50% of the world population of cattle, pigs and goats. In the world's scale the milk cows amount to about 17.5% of the total number of cattle. Milk production is predominant only in central and Eastern Europe with 51% share of cows in total number of cattle (**Table 11**).
Number and structure of farm animals depends not only on natural conditions (resources of feed staffs), but also on other factors (religion). Number of pigs is, of course, very limited in Islamic countries.

Table 10 - Main crops: a - Cultivated Area (10^6 ha); b - Yield (t/ha); c - Labour input (h/ha) [*Source: Calculations based on 8; 14; 23; 25; 29 and 30*]

SPECIFICATION		GROUP									
		I	II [a]	II [b]	III	IV	V	VI	VII	VIII	IX
Four cereals	A	59824	220	32399	31397	47238	14552	72139	40361	3635	9700
	B	2.515	3.48	5,30	2.71	0.94	0.91	2.91	1.78	1.52	2.19
	C	10	50	15	20	16	16	90	60	400	80
Rice	A	1473	1801	451	16	146	275	132214	1471	7247	5724
	B	6.70	6,22	6.02	3.31	2.81	2.46	3.80	6.02	1.60	3.19
	C	70	400	100	120	110	110	420	330	1200	400
Maize-grain	A	30579	0	4182	8013	880	413	41470	2610	23182	26102
	B	8.42	0	9.52	4,15	0.91	2.68	3.89	3.77	1.41	2.91
	C	13	0	18	25	20	20	160	90	520	120
Sorghum	A	3694	0	107	36	20	9	13025	986	22639	3926
	B	3.86	0	5.80	1.28	0.60	1.44	1.17	1.57	0.86	3.12
	C	10	0	15	20	16	16	90	60	400	80
Lentils	A	519	0	31	7	1	2	1713	1036	57	31
	B	1.26	0	0.77	0.64	0.75	1.13	0.76	0.89	0.70	0.86
	C	12	0	16	21	17	18	100	80	430	90
Rape seed	A	6998	1	3105	981	139	14	13543	19	153	80
	B	1.42	1,86	3.10	2.21	0.75	0.36	0.85	5.37	0.54	2.35
	C	8	45	11	14	10	10	60	30	400	60
Soybeans	A	29689	83	490	318	404	3	16620	129	872	22082
	B	2.62	1.75	3.21	1.73	0.69	1.33	1.35	1.78	0.95	2.47
	C	8	140	10	15	11	12	160	90	400	130
Beans	A	916	71	208	373	2	25	13962	308	3189	6637
	B	1.77	1.84	0.56	1.27	0.75	1.00	0.575	1.35	0.64	0.72
	C	8	140	10	15	11	12	160	90	400	130
Pulses	A	4612	72	2106	1470	1213	395	35527	4078	13388	7248
	B	1,54	1.85	2.94	1.87	0.82	1.05	0.60	0.89	0.49	0.74
	C	8	140	10	15	11	12	160	90	400	130
Sunflowers	A	1568	0	2255	4664	4166	308	3209	809	744	3507
	B	1.65	0	1.56	1.13	0.72	0.35	0.92	1.36	0.95	1.63
	C	21	0	29	39	35	35	115	89	530	104
Potatoes	A	766	104	1408	4564	3260	395	5086	786	501	1080
	B	35.86	32,69	34.35	14.51	9.60	10.50	15.77	19.47	8.39	14.16
	C	21	160	27	50	40	40	200	140	550	150
Cassava	A	0	0	0	0	0	0	3347	0	10452	2389
	B	0	0	0	0	0	0	13.37	0	8.22	11.69
	C	0	0	0	0	0	0	200	0	550	200
Sugar beet	A	602	69	2056	1994	806	37	518	821	0	52
	B	50.27	53.80	63.17	17.58	13.40	15.89	27.43	38.12	0	59.36
	C	25	190	30	50	40	40	200	180	0	150
Sugar cane	A	1114	23	0	0	0	0	8678	169	913	8539
	B	86.55	63.56	0	0	0	0	62.08	101.98	50.44	64.68
	C	100	750	0	0	0	0	900	800	1500	900
Vineyards	A	354	21	3490	988	70	311	325	1216	107	457
	B	17.81	11.95	7.11	5.24	4.29	4.66	12.12	7.21	12.21	11.29
	C	70	4200	60	120	100	110	600	200	5000	4000
Groundnuts	A	622	12	5	10	0	13	13531	138	8780	693
	B	2.93	2.45	5.8	1.00	0	1.69	1.50	2.31	0.81	1.96
	C										
Cotton (seeds)	A	4777	0	546	26	0	2656	17302	1559	3988	2353
	B	1.95	0	3.08	0.81	0	1.75	1.45	2.77	0.91	1.40
	C		0			0					

Table 11 - Animal production indicators [*Source: Calculations based on 8*]

SPECIFICATION	GROUP									
	I	II [a]	II [b]	III	IV	V	VI	VII	VIII	IX
Total cattle, 10^3	162183	4700	86366	38146	31700	15445	406988	33137	194479	345241
dairy cows, %	*10*	*28*	*26*	*51*	*44*	*44*	*13*	*44*	*16*	*15*
other cattle, %	*90*	*72*	*74*	*49*	*56*	*56*	*87*	*56*	*84*	*85*
Pigs, 10^3	77419	9800	121807	60614	17305	1580	567375	530	20665	76519
Sheep, 10^3	205425	16	120246	23369	17125	34218	247343	177671	146031	92667
Goats, 10^3	8885	29	12501	4318	1632	3061	385870	69242	177723	36733
Chickens, 10^6	1993	306	1025	428	405	65	5464	1042	705	2045
Heads per 100 ha of AUA										
Total cattle	15.2	95.0	57.2	29.9	15.0	5.6	38.9	9.1	12.6	46.0
dairy cows	*1.6*	*26.3*	*15.0*	*15.4*	*6.6*	*2.5*	*5.0*	*4.0*	*2.0*	*6.7*
other cattle	*13.6*	*68.7*	*42.2*	*14.5*	*8.4*	*3.1*	*33.9*	*5.1*	*10.6*	*39.3*
Pigs	7.2	198.1	80.7	47.6	8.2	0.6	54.3	0.1	1.3	10.2
Sheep	19.2	0.3	79.7	18.3	8.1	12.5	23.7	48.6	9.4	12.4
Goats	0.8	0.6	8.3	3.4	0.8	1.1	36.9	19.0	11.5	4.9
Chickens	186.3	6185.6	679.2	336.0	191.9	23.7	522.5	285.2	45.5	272.6

8. Conclusions

The analysis carried out confirmed the existence of considerable differences between the various regions of the world in terms of yields, agricultural practices adopted, intensiveness of human labour, production costs, profits obtained etc. This diversity of situations is ascribable not only to the specific climate, pedological cultural and social conditions which exist in the different areas, but also to the varying levels of mechanisation adopted and to appropriateness, or lack thereof, of the methods and machinery currently in use. All this needs to be taken into account when evaluating the local requirements for a new agricultural mechanisation capable of assuring "a long-term world food supply". After having defined, in line with the above criteria, the most appropriate characteristics for the various machines in technical and management terms, it is then necessary to make these characteristics known, divulging them and recommending them in the various countries to the governments, farmers and manufacturers, so as to effectively accomplish the proposed objectives.

This is undoubtedly a difficult task, but one that must be undertaken because – in the absence of any realistic prospects for significantly increasing the cultivated agricultural surfaces – it is imperative not only to create a functional and reliable distribution system which can ensure that foodstuffs effectively reach the populations for which they are intended, but also to increase agricultural production through:

- increasing crop yields especially in the less developed regions;
- minimise post-harvest product losses, both inside and outside the farm;
- develop production flexibility to be able to adapt to changes in demand;
- safeguard the environment, also by optimising the utilisation of energy and other inputs and then by using on appropriate mechanisation.

This problem of an appropriate mechanisation, is an extremely wide-ranging one, which requires in depth technical analysis and a holistic approach. To solve this problem, mechanisation needs to be considered not just in technical terms, but also as a component in a system where development relies upon establishing a series of essential "collateral" activities within the various countries. These concern networks of: applied research and testing centres; extension services; after-sales services; contracting companies; education and training schools, etc. All this with the ultimate objective - once the political and legislative aspects specific to each region (or country) have been acquired and resolved - of promoting the development of the sector.

References

[1] **Clarke L.J, Friedrich T.**, 2000. *Increasing food production and protecting resources: the role of Agricultural Engineering.* Proceedings of CIGR XIV World Congress, Tsukuba, December

[2] **Sharples J, Sullivan J.**, 1992. *A Gatt agreement, policy reform and the global farm machinery industry*. Proceedings IV Club of Bologna meeting, Bologna, November

[3] **Finch et Al.**, 1957. *Elements of geography: physical and cultural*. Plenum Press, New York and London

[4] **Duckham et Al.**, 1970. *Farming systems of the world*. Chatto & Windus, London

[5] **Krause R., Poesse I.R.**, 1997. *The role of Agricultural Engineering in the development process*. AMA, n.2

[6] **Magette W.L.**, 2000. *Are we helping the farmers enough?* Proceedings FAO-RAMIRAN 2000 workshop, Gargnano, September

[7] **Bernardini O.**, **Galli R.**, 1993. *Dematerialisation: long-term trends in the intensity of use of materials and energy.* Futures, May

[8] **FAO**, 1999. *Production yearbook*. Rome

[9] **Snobar B.A., 1992.** *Contractors in Agricultur. A preliminar analysis in the developing countries.* Proceedings IV Club of Bologna meeting, Bologna, November

[10] **Pellizzi G., Fiala M.**, et Al., 1991 and 1999. *Country reports: an overview*. Proceedings III and X Club of Bologna meetings, Bologna, November

[11] **Agency Government of Japan**, 2001. *Japan Statistical Yearbook 2001*. Statistical Bureau Management and Coordination

[12] **Farm Machinery Industrial Research Corp.**, 2001. *Farm Machinery.* Statistic from Farm Machinery Yearbook, 2001 edition

[13] *1998* (Statistical Yearbook of Ukraine), Kiïv, *Statisticnyj Scoricnik Ukraïny*

[14] **Pellizzi G.**, 1997. *Meccanica e meccanizzazione agricola (Agricultural machinery and mechanisation)*. Edagricole, Bologna

[15] **Fiala M., Pagani A., Pellizzi G.**, 2000. *Guidelines for the technology transfer in Developing Countries*. Proceedings XI Club of Bologna meeting, Bologna, November

[16] **Wang. M.**, 2001. *Possible adoption of precision agriculture for developing countries at the threshold of the new millennium*. Computers and Electronics in Agriculture, n.30, Elsevier

[17] **Auernhammer H.**, 2001. *Precision farming: the environmental challenge*. Computers and Electronics in Agriculture, n. 30, Elsevier

[18] **ILO**, 2000. *Yearbook of Labor Statistics*. Geneva

[19] *Statistisches Jahrbuch 1997 für das Bundesrepublik Deutschland*. Verlag: Metzler/Poeschel, Stuttgart

[20] **GUS**, 2000. *Rocznik Statystyczny Rzeczypospolitej Polskiej 2000 (Statistical Yearbook of the Republic of Poland)*. Warsaw

[21] **Pawlak J.**, 1998. *Stan motoryzacji polskiego rolnictwa na tle krajow UE. (Mechanical power in Polish agriculture on EU background)*. Wies Jutra n. 3

[22] **OECD**, 2001. *Energy prices & taxes*. Quarterly statistics. Third quarter 2000. Paris

[23] **OECD**, 2000. *World Energy Outlook*. International Energy Agency. Paris

[24] **Pawlak J.**, 1999. *Energy inputs in Polish agriculture*. n.2, Technical Sciences

[25] **Ministry of Agriculture, Forestry and Fisheries of Japan,** 1997. *The 73th Statistical yearbook*. Tokyo

[26] **USDA**, 1997. *Agricultural Statistics 1997*. United States Printing Office, Washington
[27] **UN**, 2000. *Statistical Yearbook*. Forty-fourth issue, New York
[28] **Hayashi N., Herodian S.**, 1993. *The rapid mechanization of Japanese agriculture and the changes this has caused*. Proceedings XXV CIOSTA-CIGR V Congress, Wageningen
[29] **Hecht H.**, **Abo-Habaga M**., 1986. *Arbeitzeitstudien in Togo, Kenia und Aegypten und davon abzuleitete Vorschläge zur Mechanisierung*. XXII International CIOSTA-CIGR V° Congress, Stuttgart-Hohenheim
[30] **Palonen J.**, 1993. *Labour, machinery and energy data bases in plant production: results.* Proceedings XXV CIOSTA-CIGR V Congress, Wageningen
[31] **FAO**, 1999. *Trade yearbook*, New York
[32] **Eurostat**, 1997. *Yearbook of Agricultural Statistics*. Luxembourg
[33] *Africa South of Sahara*. 27th Edition. Rochester, Kent