Crop management for processing tomatoes in the year 2000

Y. Dumas

Number 301
January 1992

ISHS
International Society for Horticultural Science

Fourth International Symposium on Processing Tomatoes

Editors
Cosme A. Argerich
Humberto R. Galmarini

Mendoza, Argentina
18-21 February, 1991

CROP MANAGEMENT FOR PROCESSING TOMATOES IN THE YEAR 2000

Y. Dumas
Institut National de la Recherche Agronomique, Station d'Agronomie, B.P. 91, F 84143 Montfavet Cedex

1. Introduction

It is hazardous to try to envision the next ten years because changes do not occur at the same rate in the various countries concerned by processing tomato : there are great differences between countries with non-mechanized production and yield increase as their main objective, and others with developed techniques and quality as a new concern. Ten years is both a long and short period. It roughly represents the time required to disseminate new technology. But technological progress (such as drip irrigation) continues to accelerate. Many changes may also appear within some fields, such as the new requirements of the processed product purchasers. Ten years may seem short for other concerns such as plant-breeding : creating and distributing a new cultivar may take a decade. So, what will the tomato crop management look like in the year 2000?

In the following sections, not all the crop management techniques are examined in detail. After an evocation of changes in the general cropping context, important points of the crop management will be analysed in relation to the main tomato development phases.

2. General context

As for other crops, success in processing tomato management requires more and more precise methods and techniques and is becoming a difficult exercise, at least in economically and technically advanced areas. Looking forward to the year 2000, it will be necessary to face various challenges which will govern the crop's future. The following three determining aspects can be emphasized.

2.1. Crop mechanization

Crop mechanization will widely spread. Of course this will vary in relation to the very different cropping systems used throughout the world (Portas et al., 1990). This trend is the result of the general need to reduce production costs, especially labour, which increase much more rapidly than the tomato selling price (Table 1). The future in crop management also tends towards an increased use of a once-over harvest, more and more by machine. This leads to cultivation constraints both at the medium and stand levels, which determine agronomic objectives and consequently technical choices (Di Candilo and Casarini, 1987, Siviero, 1990, Dumas, 1990 a).

As tomato fruit must be processed as soon as it is ripe, single harvest extension must be accompanied by the organization of raw material production (Lecocq and Vayson, 1985) to supply the processing plants for a fairly long time, such as in California, but also to properly distribute farm work throughout the growing season. This requires a sequential harvesting programme and crop settlement planning. This type of planning is efficient in areas with regular and stable climate and will be more critical in areas with a more variable annual climate, such as in the South-East of France (Table 2) where two fields seeded within a 45 day interval may be harvested within a fortnight interval if spring has been cold and summer hot.

2.2. Control of raw material quality

Raw material quality, i.e. all the characteristics of tomatoes delivered to the processing plant, will become an objective per se. Various types of products will have to be elaborated in the fields, depending on their processing destination and crop management will need to be adapted to obtain the desired product. The main quality parameters are soluble solids, pH, colour, insoluble solids and soluble pectins. But very restrictive quality standards will soon have to be met for nutrition (mineral elements, vitamins), taste (acids) and health standards (bacteriology and toxicological harmlessness).

A change in focus will occur. Until now, maximum quantitative yields were aimed at, and, more recently, high yields at the lowest cost, which generally resulted in lower production levels. In future it will be necessary to know how to produce fruit with a high given quality probably by decreasing quantitative yield.

2.3. Respect for natural resources and environment

It will be necessary to produce without pollution. An increasing public awareness of environment and natural resource problems has developed throughout the world. Open field crops are suspected to pollute soils and groundwater and to be also major consumers of energy and water which must be conserved. Processing tomato crop management will require an effort in input management (supply reduction and increased use efficiency) in relation to production goals, instantaneous crop and medium states and their probable changes over time.

This is the framework which will have to be taken into consideration by processing tomato crop management in the various physical and socio-economic situations, as production will only thrive if it continues to provide sufficient returns for the grower. The tendency is to use a crop management for a given production in quantity and quality, where each of these two parameters has its own change margins. Farming is thus becoming an entreprise but an entreprise whose goals, though fixed in advance, can possibly change over time due to aleatory factors which disturb the production achievement.

3. Crop management

Crop management must be considered as a consistent whole with regard to production aims, initial crop conditions and intermediate stages or objectives eventually fixed by the grower which are to be achieved through the available means, i.e. work organization on the farm, equipment, funds and information.

To simplify the presentation in relation with yield components, the tomato development cycle can be schematically divided into three main interdependant phases (Table 3) :

- Stand establishment and vegetative growth phase : this determines the number of plants per area unit, the stand structure and an earlier or later flowering.
- Flowering and fruit-setting phase : it leads to the number of fruits per plant and, along with the previous phase result, determines the number of fruits per area unit, which is the main quantitative yield component.
- Ripening phase : at the end of this phase average fruit weight and its technological characteristics are fixed. In fact, fruit growth overlaps the last two phases.

Crop management must aim at satisfying the goals of each phase to obtain the final desired product in a crop suited to a single harvest, particularly by machine. The grower will have to think of the management of each phase according to the others. For convenience's sake, crop management elements are presented here phase by phase while the main aspects and interactions are emphasized.

3.1. Vegetative growth phase

All the technical operations occuring before or accompanying crop establishment are of primary importance due to their consequences on the medium which largely influence crop potential. The objective is to obtain a stand with a uniform development stage and spatial regularity whose growth and development rate is as close as possible to the potential rate determined by climatic conditions (intercepted energy).

3.1.1. Crop establishment

For crop settlement, transplanting and seeding on raised beds will remain complementary methods with equivalent yield potentials (Gerber, 1981).

Transplanting will be more and more achieved with plant-tray seedlings using automatic machines. Growing them in nurseries remains technically rather difficult and expensive but permits a fairly good delivery schedule. Establishment operations must therefore be performed carefully, particularly with the expansion of hybrids.

Direct-seeding is already used 100% of the time in certain regions with a suitable climate (California). Because of the necessity of saving costs and labour organization it will be largely extended to numerous regions whose warm season is long enough. In suboptimal conditions, germination, emergence and plant establishment represent critical periods on which the production potential depends. Seeds must be placed under favourable conditions somewhat close to the nursery conditions. Many studies have shown the advantages of seed priming which could spread. Priming with potassium nitrate or phosphate enhances seed vigour i.e. germination rate (Argerich and Bradford, 1989, Argerich et al., 1990) and reduces emergence time (Leskovar and Sims, 1987) particularly under low temperature conditions (Barlow and Haigh, 1987). It is a way to make emergence more uniform and to obtain a more homogeneous stand, although an initial growth advantage does not necessarily improve ripening time, total yield or fruit sugar content (Alvarado et al., 1987). The physiological mechanisms involved in priming are not well known. Haigh and Barlow (1987) found that germination was more dependant on the ionic strength than on the osmotic potential of the imbibition solution. The various efficient substances might exert a stimulating effect on enzyme system activity during the first germination stages (Puls and Lambeth, 1974).

Seedling establishment also depends on physical characteristics of the seed-bed. In addition to good temperature conditions and moisture content, maintaining a soil structure conducive to water and air movement and to seedling emergence is very important. On easily crusting soils it is necessary to protect the seed-bed by applying a plastic mulch or soil conditioner. The latter may produce a synergic effect on the plant mineral nutrition (Wallace and Abouzamzam, 1986).

Mineral nutrition : The tomato plantlet is autotrophic a few days after emergence (Suniaga and Dumas, 1990), as nitrogen and phosphorus absorption begins on the day of emergence when photosynthesis starts after potassium absorption has already began. During the period of time until flowering mineral nitrogen availability in the medium influences growth and development (Suniaga Quijada, 1990) : too little N in the solution (e.g. 2 meq N l^{-1}) results in a general delay, and too much (e.g. 18 meq N l^{-1}) first causes root growth rate to decrease and then yields a great number of small non-viable trusses. It thus seems very important to know the mineral N content of the soil to control it, both to correctly manage the crop and to avoid waste. It is also known that a high P availability in the soil increases growth and development rates, particularly from emergence to early flowering. However, the root system is very small during the vegetative phase and it is not necessary to enrich the entire arable soil volume : banding a moderate amount of triple superphosphate under the seeds is sufficient to achieve the required effect (Dumas,1989). A high individual growth rate is advantageous in competition against weeds on the row. Banding low amounts of N fertilizer on the rows at the first truss stage is very efficient for young tomato seedlings and disadvantages nitrophilous weeds which emerge off the rows.

Plant spatial distribution (arrangement and density) may strongly influence yield potential, but it depends on the cultivar vine-size (Frost and Kretchman, 1988). Growing a compact plant type at high density on double rows results both in a more rapid and important soil covering. Consequently, the stand intercepts more light. Within certain limits tomato is able to compensate for density variations by varying branch number and then the numbers of truss and fruit per plant. But Figure 1 indicates that the capacity of a seeded stand to compensate is highly dependant on the medium conditions and stand density largely influences fruit number (main yield component), as well as, to a lesser extent, average fruit weight. Therefore, it is not easy to choose a density objective or to decide how to manage adjustments in a field, where density is thought to be inadequate. Nichols et al. (1973) have shown that the yield-density relation is of course dependant on the cultivar and that the concentration of maturity increased with the stand density. High density and double-row methods may be revised when using expensive hybrids and large-vined and high solid cultivars (May et Valencia, 1990) or to ensure better crop protection. Stand deficiencies in plantations may lead to a decrease in yield potential. Stoffella and Maynard (1988) have found that replanting was profitable only with 30% stand reduction in a stressed environment and if it was performed within two weeks after initial transplanting.

3.1.2. Crop protection

Pest control : Crop protection will first of all aim at preventing seedlings or transplants from being cut by predatory animals or destroyed by fungus. There is no way to forecast infestation levels and the only thing to do is to perform a preventive pest control preferably with banded applications and low volumes per hectare placed close to the organs to be protected. For leaf pests, sprays should be used in accordance with warnings and field observations based on infestation thresholds when they are known (Bues et al., 1985). For example, the more vigorous the crop, the higher the aphid infestation threshold may be (Dumas, 1990 a).

Weed control : Weeds are generally well controlled in transplanted fields, but weed control is a major problem in seeded fields. It is often reported that the critical period for weed competition is from 30 to 45 days after seeding date (Duranti and Carone, 1983). Yield losses associated with weed quantity could be attributed both to reductions in light levels because of shading and to competition for water resulting in stomatal closure (Weaver and Tan, 1987).

Although weeds such as *Amaranthus retroflexus* L. and *Echinochloa crus galli* L. are the most aggressive against tomato (Caussanel et al., 1989) the "*Solanum* sp." complex, particularly black nightshade (*Solanum nigrum* L.) pose the greatest problems in seeded crops due to the biological density factor (Branthome, 1990). A hyperbolic model provided an excellent fit to data on tomato yield losses, which were lower for sown tomatoes grown at higher density (45 000 against 33 300 plants ha^{-1}) in twin rows, as a function of nightshade density (Weaver et al., 1987). Yields were significantly reduced at infestation levels above 1 plant m^{-2} (Damato and Montemurro, 1986) and Caussanel et al. (1989) showed that 3 plants m^{-2} from the tomato stage of 3-5 leaves to harvest were sufficient to reduce yields by 35-45%. The most critical period of interference was found to be from early flowering through fruit-set with a threshold of less than 1 plant m^{-2}. It is necessary to develop control schedules adapted to cultural situations during the vegetative phase : emergence in clean soil, maintaining low populations and total cleaning before flowering. Presently there is no chemical solution which completely destroys nightshades without reducing tomato yield. Control depends on strategies consistent with crop specificities (Branthome, 1990), e.g. use of mixtures of pre- or post-emergence herbicides combined with complete diquat applications before tomato emergence or banded diquat applications later and with hoeing. Localized soil desinfection is efficient during stand establishment. Mechanical or hand hoeing also helps remove crusts and favours water and air circulation through the soil, although superficial roots must be preserved.

The next step will be genetic. Currently no useful natural tolerance to post-seeding or post-emergence herbicides efficient against *Solanum nigrum* L. have been found in genus *Lycopersicon* (Damidaux et al.,1990). Resistances to certain efficient herbicide molecules will undoubtly be introduced soon into the tomato genome using biotechnology. However, one must take care not too over privilege strategies which could limit the range of cultivar choices for growers and lead to a more and more intense use of herbicides. Other methods have to be explored, such as biological control by weed parasitism (Putman, 1990, Giannopolitis and Chrysayi, 1989, cited by Branthome, 1990). Management solutions for the very near future must be based on integrating cultural and chemical methods : crop successions, soil preparation, banding of adapted fertilizer amounts, hoeing and banded applications of herbicide allowing spray volume savings. Unfortunately, the best way to water young tomato seedlings or transplants to achieve good stand establishment remains sprinkler irrigation which favours weed emergence and development!

3.1.3. Soil structure and rooting

Under common management conditions, potential yields widely depend on root system extension (Dumas, 1982) through the level and regularity of water and nutrient supply. Root depth and distribution depend on structure and porosity of the various soil layers. For three contemporary seedling (UC 82) situations on nutrient-rich loamy-clay soils in the South-East of France, Figure 2 shows the root depth changes over time and the soil bulk density values measured between -5 and -60 cm. Situation (a) presented favourable soil structure conditions and root growth rate was high. At the 1st truss stage, the taproot point was -40 cm deep, i.e. four times the shoot height; yield potential was 90-100 t ha^{-1}. In situation (b) the soil was a bit more compact below -20 cm and root growth rate was lower and final rooting depth smaller. Yield potential was 60-70 t ha^{-1}. Situation (c) represented poor rooting conditions with a taproot point no deeper than -15 cm at the first truss stage which was also delayed. The soil profile showed a drastic compaction in the ploughed layer from -10 to -30 cm and a typical plough-pan between -30 and -40 cm, with bulk densities >1.70 g cm^{-3} able to completely stop root system progression, as Greig et al. (1964) observed, and similar to responses obtained by Ruff et al. (1987) in studies on root volume restriction in containers. Under such field conditions no more than 30 t ha^{-1} could be expected.

Thus, soil structure is very important as a basic condition of crop success. Many problems can occur as a consequence of using heavier and more powerful equipment with increased mechanization. Soil moisture conditions during traffic or tillage operations play an essential role in structure discontinuities. Both for current soil tillage (choice of equipment, timing) and correction of structure accidents (e.g. subsoiling a plough-pan), decisions must be made through the observation of the soil profile and utilization of simple predictive models which have to be improved region by region.

Soil profile characteristics must allow the best transplant and seed settlement and rapid plantlet growth to yield a vigorous stand as well as remaining favourable to the following reproductive phase.

3.2. Flowering and fruit-setting phase

It corresponds to the period of the highest rate of dry matter accumulation and plant requirements. The aim generally is to maximize the rate of appearance of fruiting sites on the plant over a month and to subsequently allow fruit growth. During this phase, the most limiting agronomic factors may be water and nutrients.

3.2.1. Nutrient supply

Plants take up nutrients from the soil solution which is supplied by soil reserves and fertilizers. Actually, it is not possible to exactly know the soil feeding capacity for the various nutrients at a given moment (Dumas, 1990 b) and consequently to decide how much fertilizer to supply and how to supply it. Nevertheless, it is necessary to provide crops with sufficient amounts of nutrients to meet their momentany and total requirements but not too much to cause losses due to leaching or insolubilisation. In fact, it is more a question of nutrient concentration in the functioning root volume of soil at any given moment than in total soil volume. Greenwood et al. (1989) found that apparent recovery of N fertilizer by various vegetable crops declined with the increase in N fertilizer; this behaviour contrasts with the well-known constancy of apparent recovery in the Gramineae and was explained mainly in terms of differences of root density due to a less extensive root system. This is a reason to try to obtain a well developed root system to intercept more NO_3-N as well as to avoid potassium deficiency which Widders and Lorenz (1979) attributed to the inability of the relatively small root systems of the determinate tomato cultivars to absorb K at a rate sufficient to meet the demands of the concentrated fruit set.

In the near future, basic knowledge of the dynamic of the main soil nutrients is expected to increase and lead to an understanding of the general variation rules which will permit fertilization forecasts according to stand requirements. Direct simple plant tests may also become useful such as nitrate tests in petiole sap (Coltman, 1987) -if they are sufficiently sensitive, precise and reliable-, as tomato reacts very quickly to nitrate content variations of the medium (Suniaga Quijada et al., 1991, same issue).

3.2.2. Water supply

Processing tomatoes are cultivated only in open field i.e. in regions with a sufficiently long warm season and generally a high water deficit. Therefore it is not surprising that more than two thirds of the areas are irrigated (Portas et al., 1990) and this proportion will increase. Irrigation management depends on many interacting factors : climate characteristics, soil texture and structure, crop development stage (water demand), rooting system extension (water extraction potential), irrigating method and equipment, water quality and availability. No recipe can be given for quantity and frequency of water supply, except that the Kc crop coefficient value reaches 1.20-1.30 during full fruit-setting.

Furrow irrigation, the most ancient irrigation system, will undoubtly continue to exist in areas well-supplied with good quality water and well-levelled fields because of its low cost, but with improvements such as automation and optimal water distribution in the fields to provide better homogeneity and limit leaching. It needs a porous soil structure to permit good lateral diffusion of water to moisten the beds in the rooting zone.

Sprinkler irrigation is a very common method but one which has disadvantages : it is labour consuming, sensitive to wind, favours soil crusting, weed emergence and desease expansion, and delays traffic. However, it is nearly indispensable to crop establishment in dry years : filling soil to water capacity, germinating seeds, transplant recovery, herbicide fixation. Farmers who use a localized method afterwards must be equipped with both systems.

Drip irrigation systems are recommended when water is limited or expensive and for shallow soils. During the last fifteen years many studies have demonstrated the interest of micro-irrigation as compared to other systems. It often improves yields while saving water (higher use efficiency), particularly in arid regions, it is less favourable to certain pests and permits mechanized handling operations. When it is controlled by an automatic station it requires a large surrounding area, which is not possible everywhere. Phene et al. (1987) have widely experimented on permanent subsurface drip installations below plough depth. Among its main advantages are : it requires less labour than surface installations, may last longer, keeps the whole soil surface dry, reduces the occurrence of soil born diseases, enhances circulation even while irrigating and allows a more efficient use of water and nutrients resulting in very high yields (Phene et al., 1990). Grattan et al. (1988) observed that it resulted in lower weed populations, but this was obtained in a region without frequent rains and during a period of low weed emergence. Such a system must be used with a succession of mostly row crops (to offset costs), where rows are always exactly in the same place.

Fertigation is the water-fertilizer management type of the future. In sandy soils Bar-Yosef and Sagiv (1982) found that total yield was linearly related to total N application rate, when N was applied daily to the irrigation water. In sand Locascio et al. (1989) found that total yields were higher with split trickle-irrigation than with all preplant-applied N and K, but equivalent on a fine sandy loam. Field experiments on fine sand (Dandler and Locascio, 1990) did not reveal any differences in fruit between fertilizer (N and/or K) trickle-injected weekly on a variable (depending on stand stage) or constant schedule; but the latter, if it is simpler to manage, may lead to a lower N use efficiency (Bar-Yosef and Sagiv, 1982).

Knowledge about drip irrigation is still fragmentary and sometimes contradictory. In fact, it is difficult to correctly manage. The quantity of water supply, varying from 40 to 80% of potential evapotranspiration according to the studies, depends on soil characteristics and it is the same for water and nutrient (e.g. N and K) circulation, including losses (Calado et al., 1990). It also depends on soil structure and root system distribution. A structure with good porosity and a deep, dense and healthy rooting are still the main objectives. They may contribute to minimize management mistakes which can very easily occur by supplying either too much or too little water as often seen in farmers' fields, with risks of important yield or quality losses. Rainfall in certain areas adds to the complexity of the situations.

3.2.3. Crop protection

Generally, during this period of time, temperatures are high so that pests are relatively infrequent and weed emergence remains limited. Weed control will consist in stopping the growth of existing weeds, which could be competitive (*Solanum* sp.), increase soil seed stock and disturb machine harvesting (*Amaranthus retroflexus, Chenopodium album, Cirsium arvense, Datura stramonium,* etc.). Chemical and some manual interventions are often necessary. Viruses and mycoplasms are detrimental to crops and tolerant or resistant cultivars must be used when they exist, as it often is inefficient to try to control their vectors. One of the most yield damaging insect pests is the tomato fruitworm (*Heliothis armigera*), particularly in late crops. It remains very difficult to forecast and estimate invasion importance even by trapping, and control must be undertaken after observation of eggs on the foliage. This can be an association of chemical and biological techniques, e.g. strong insecticide at the beginning to kill many forms, followed by regular (e.g. weekly) *Bacillus thuringiensis* sprays (Dumas, 1990 a) or *Trichogramma* releases. During the phase of important foliage development, pest control will be better ensured by atomised spraying which enables the active ingredient to reach any part of the plants.

3.3. Ripening phase

3.3.1. Concentration of maturity and quality

Many factors may influence over the whole cycle. Results in literature are not always consistent, particularly about the consequences of nutrient and water availability; this can be explained by the varied experimental situations which generate different interactions. However, the ripening phase conditions are of primary importance.

Maturation must end by crop senescence without regrowth to achieve the concentration of maturity and facilitate mechanical harvesting. This is possible only where low mineral nitrogen and water are available in the soil profile, as generally lower temperatures allow leaf and truss regrowth when fruit demand for assimilates is lower. A better quality (higher soluble solids) requires water shortage during part of the ripening period but also necessitates to maintain a high leaf to fruit ratio. On the contrary, it is necessary to keep plants in functioning conditions as late as possible to let the largest number of fruits grow (high yield). This requires a good water supply, as Wolf and Rudich (1988) found that water stress shortened the duration of fruit growth and accelerated the ripening rate. A good water supply is also needed to maintain late covering foliage to achieve better fruit colour by ripening in the shade of the foliage. All these aspects lead to a difficult compromises in management.

Sander et al. (1989) in California found that yields of red tomatoes increased with increasing trickle irrigation water and the concentrations of soluble solids, total solids and pH decreased, while colour, fruit size, and acidity increased, as did the yield of soluble solids and total solids per hectare. Many studies have pointed out a conflict between high yields obtained from high water supply and low soluble solid contents. May et al. (1990) suggested managing soil moisture stress either through depletion levels during the cycle or irrigation cut-off dates prior to harvest. The latter factor strongly modified yields and the percentage of solids although solid yield was stable. The choice of the cut-off date will depend on many parameters : - What is the farmer's goal for yield and quality : more fruit per hectare or a higher solid content? - What is the real moisture stress imposed on the crop, as it is related to the available water reserves, including soil moisture content and rooting characteristics? - What will be the intensity of the climatic demand? It is difficult to forecast it beyond 5 days. - What is the crop state (root and foliage health)?

Other quality criteria will have to be considered. Fruit colour is one of them : for example external and internal blotchy ripening of fresh market tomatoes was less severe with trickle-applied N supplied in the form of N + K or N than with preplant-applied N (Dangler and Locascio, 1990). Flavour may be improved, as well as overall fruit quality by salinity from diluted seawater irrigation from the first breaker fruit stage in certain situations without yield loss (Mizrahi et al., 1988). Much is currently known about greenhouse tomato but there is still much to be done on processing tomato.

The use of ripening regulators under normal conditions (medium temperatures, recommended doses for slow foliage ageing) favours maturity concentration and quality is not modified (Branthome and Ple, 1990). These aspects have been developed by Leoni (1991, same issue). In fact, faced with consumer pressure, it may become necessary to find ways of cropping without regulators.

3.3.2. Crop protection

Weeds will be removed if they are suspected to disturb harvest or to considerably increase the seed stock. Tomato fruit quality, as measured by soluble solids, acidity and colour, was not influenced by the various weeds or densities in various studies (Monaco et al., 1981, Damato and Montemurro, 1986).

To keeping fruits with a good aspect on the plant till harvest it is necessary to protect the first trusses from overmaturity and accompanying diseases by using appropriate fongicide sprays and to protect the foliage from drying up and the fruits from sunburns. But rules on pesticide residues in fruits will be more and more strict. International unity is now indispensable to define the pesticides used and the tolerable residues. It is beginning at the European level. Reducing chemical applications requires the development of predictive systems and using forecast-scheduled spraying. Currently a common solution consists in frequent observations of test-fields with a warning when thresholds are exceeded.

At this stage of the discussion crop management has reached harvest time. Much has to be done not to decrease quantitative and qualitative production during harvest, handling and transport.

4. The place of tomato crop in crop successions

Crop management must also be thought of in terms of crop succession. Many crops respond positively to "crop rotation" as opposed to monoculture. This seems true for processing tomato. But few experiments or survey studies have yet been performed. Freitas and Faria (1981) found that cropping tomatoes in rotation with maize and beans or with a natural fallow vegetation yielded higher productivity than continuous cropping. Generally speaking, crop specialization trends to increase sensitivity to crop enemies and dependance on chemical control and to increase soil structural degradation by the repeated use of the same soil tillage and crop management methods, often under suboptimal conditions. In France, producers often speak about "soil sickness" when they can no longer achieve good yields in a field in spite of usual management techniques and they usely look for "new fields" where no tomato crop has been grown for at least 20 years. Field surveys showed that "soil sickness" could be associated with the frequency of tomato crops or other vegetables in the succession but not with soil analytical characteristics. "Soil sickness" is not a relevant concept as it may correspond to varied situations caused by different factors which may more or less coexist (Bouhot and Dumas, 1983) : stunted shoot system, low fruit number and low average weight, small root system with necrosis symptoms can be observed as well as weed infestation, high proportion of compact structure in the soil profile, poor soil fauna (earthworms) and microflora activity. Such situations need a pluridisciplinary diagnosis, including cropping system.

Preceding crops influence the physical, chemical and biological properties of a soil. From a field sample survey, Vergniaud et al. (1984) demonstrated that weed species groups in tomato crops were mainly related to the precedent crops and the weed control methods. It may be profitable to grow tomato after a spring crop which can safely catalyse the active ingredient of a herbicide very effective on

Solanum sp. (sunflower, sorghum, soybean, spinach, peas, onions, etc.). Weed suppression may be improved by using allelopathic crops and companion crops in the rotation and by mulching with crop residues. Labrada and Perez (1988) recommended *Phaseolus vulgaris*, maize, sorghum and cucumber as trap crops for *Orobanche ramosa* as they stimulated *O. ramosa* seed germination but were not parasitized. On the contrary, forage and cereal crops favour click beetle and McKeown et al. (1988) observed that populations of plant parasitic nematodes were stimulated by rye and strip tillage and that bacterial diseases (*Xanthomonas vesicatoria* and *Pseudomonas tomato*) were increased by strip tillage in one season. As a positive nutritional aspect, residual N from a sugar beet crop had a greater impact on tomato yield than fertilizer applied specifically to that crop, and crop rotation and efficient fertilization practices could minimize N losses by leaching (Osterli and Meyer, 1977). In this context, organic matter must not be forgotten and residues of certain crops in the succession may be useful for micro-fauna and flora activity (soil structure) and to conserve chemical fertility, e.g. for N and P if fertilizer supplies are low.

There is a need to study the effects of previous crops on the medium and the consequences on the following crop management. The farmer's practices (land preparation and crop management) tend to favourably modify the medium characteristics for tomato. But instead of simply enduring and correcting them by using many expensive techniques, it may be possible to try to better control the previous crop management to achieve a field state more favourable to tomato in terms of soil structure, nutrient status, weeds, pests and diseases, etc. Of course the choice of crops is the farmer's responsibility and depends on the physical and socio-economic context. But in the future these aspects must be kept in mind and better controlled in integrated cropping systems. Long term evaluation of cropping system effects on yield and on environment should be performed.

5. Future viewpoint for growers and researchers

There is some distance between growers and researchers. Growers think about their practices for tomato crops within a constraint framework at the farm level which includes problems of equipment, time distribution of the work, financial availabilities, personal work or life style, etc. They have to solve synthetic problems and often make decisions in relation to the whole farm management rather than crop by crop. On the contrary researchers tend to reason more analytically at the single crop level in a field during a season independantly of farming situations. Collaboration between researchers and growers should occur in two directionss : developments of tools to measure indicators and forecasting.

Growers' attitude will probably change gradually. They will have to find more time to observe, to measure parameters and to keep informed, to be able to diagnose, forecast and finally decide. To do this well they will need indicators on soil and plant states, which can easily be used. In some cases decision-making may automatically originate from data collected by sensors in relation to a predetermined threshold. Growers will need to learn, but their acceptance of innovation will no doubt be difficult, as many of them will have to reformulate or reinvent the new technology by themselves (Grieshop et al., 1988) or through discussions inside their professional group.

5.1. Tools for indicator measurements

There already exist tools to help decision-making but they are not always practical on the farm. **Irrigation** is among the more advanced chapters. A great effort has been made to promote irrigation assistance systems by scheduling based on predicted or directly measured soil or plant water status. Various principles have been utilized. The water balance model requires information on root water extraction activity throughout the soil profile, canopy state, crop coefficients and climatic data; it may be linked to a regional agrometeorological assistance system. Soil water status may be estimated using a neutron probe or more commonly tensiometers; but with drip irrigation systems the difficulty lies in placing tensiometers correctly due to specific moisture distribution, and many mistakes are made by growers in addition to problems of going off scale. Han (1988) found that the climatological method was as accurate as the neutron probe method and was more convenient and less expensive; but few growers use it essentially because it is "too complicated" (Wolfe, 1990). Growth stage and root depth observations are time consuming and errors associated with root depth estimation may limit the accuracy of ET estimates. But there are also other promising approaches for the future. Real time scheduling with automated soil matric potential sensor measurements was successfully experimented on by Phene and Clark (1990). Crop Water Stress Index (CWSI) quantifies plant water stress by measuring plant canopy temperatures with an infrared thermometer (Calado et al., 1990) and appears to be useful in irrigation management. Measurement of leaf water potential or micrometric organ (stem or fruit) size variations (Huguet, 1985) are other possibilities. Remote sensing from airplanes or satellites with connexions to computers and automatic equipments will be a further step which will even make it possible to determine what kind of stress a crop is undergoing (water deficiency or excess, nutrition, disease, pest, etc.). But it will be a long time before all these sophisticated technologies can reach farms. Within the next ten years more growers will probably be using microcomputers and consultants for crop management but only if they find truly user-friendly programmes for scheduling. Scheduling software conception is difficult because it must be easy to use and yet complex enough to maintain accuracy. That is why in the near future education that emphasizes the simplest guidelines and concepts should be continued for most growers.

As for **fertilization**, measurements on plants or soil are difficult and unautomatized. There are no indicators with rapid responses and there are few models generally adapted to very particular situations. However, estimated balances are needed in relation to objectives and unpredictable events.

Crop protection is also difficult to forecast. Expert systems are being developed for more reliable diagnosis. But the tendency is still more towards anticipation or preplanned routine spray schedules than spraying on-demand when necessary, because of the high risks. Progress is expected to find new specific and systemic ingredients which react at very low doses, to use biological control (natural enemies regulating pest populations) and above all to develop genetic resistance. The key for success will lie in an "integrated pest management" efficiently using available strategies to control populations at an acceptable level with a minimal use of chemical pesticides.

It is important to note that an efficient use of all these various sensors requires some knowledge of the whole set of parameters i.e. requires modeling the crop as a whole.

5.2. Aids for decision-making

Formerly, cropping utilized traditional methods established over a long time period through trial and error successions and included the main possible environment variations. Most of the available studies have dealt with specific topics in particular situations; they often reported results that varied from year to year or place to place and it remains difficult to establish general relationships between these results due to the large number of variables involved : cultivar, planting date, global radiation, water and nutrient availability, impact of pests, etc.

There is a need for synthetic studies and theorization. It is necessary to "manage" the crop towards a final aim through a succession of sub-objectives without failing. Researchers have to propose "estimated crop management schedules" which could integrate parameters on field history determining its initial state before tomato, grower's means and farm functioning, average climate and risks of extreme events, production objectives and objectives of future utilization of the field. Modeling is expected to help provide simulations before decision-making. Many studies have been started in this direction over the past few years, but essentially under greenhouse conditions. Management requires predictive models based on crop physiology and environment characteristics (Wilson et al., 1987) i.e. operational tools for work close to the field conditions. It seems important to pay attention to the variability of both soil and plant canopy over space and time (Bussières, 1990). This of course involves interdisciplinary research to organize the scattered knowledge into consistent and quantitative schemes. More and more complex situations will also require research to be developed at the farm level.

6. Conclusion

All the partners involved in field production process must be aware that cropping for the highest yield is no longer the only goal. Research and Development Services now have to work to promote integrated cropping systems. They must get ready for the enforcement of next legal measures to severely reduce pesticide and fertilizer use. New production systems will have to guarantee their own viability with little or no output to the environment and without risks for the consumer, to maintain soil fertility and generate an acceptable income for the grower. These systems will involve a high input of available knowledge to produce better food in a better and more economical way.

Advanced technology management will undoubtedly be more often adopted in developed countries, particularly in areas favourable to production (large farm structures, good physical and economic environment) which may cause some changes in the distribution of production areas. On the other hand, it is expected that less developed regions may somewhat compensate for their technical backwardness, as they will be able to take advantage of the available knowledge for rational crop management without experiencing a period of high productivity with its disadvantages in terms of use of excessive quantities of chemicals and energy.

Acknowledgements : I wish to express grateful thanks to Ph. Bussières for his critical reading of the manuscript.

References

Alvarado, A.D., Bradford, K.J. and Hewitt, J.D., 1987. Osmotic priming of tomato seeds : effects on germination, field emergence, seedling growth, and fruit yield. J. Amer. Soc. Hort. Sci. 112 (3): 427-432.

Argerich, C.A. and Bradford, K.J., 1989. The effects of priming and ageing on seed vigor in tomato. J. Exp. Bot. 40 (214): 599-607.

Argerich, C.A., Bradford, K.J. and Ashton, F.M., 1990. Influence of seed vigor and preplant herbicides on emergence, growth, and yield of tomato. Hort-Sci. 25 (3): 288-291.

Barlow, E.W.R. and Haigh, A.M., 1987. Effect of seed priming on the emergence, growth and yield of UC 82B. Acta Hort. 200: 153-164.

Bar-Yosef, B. and Sagiv, B., 1982. Response of tomatoes to N and water applied via a trickle irrigation system. I. Nitrogen. Agron. J. 74 (4): 633-637.

Bouhot, D. and Dumas, Y., 1983. Fatigue des sols en culture de tomates de plein champ. in La fatigue des sols, 23ème colloque SFP, Les Colloques de l'INRA, n° 17: 77-81.

Branthome, X. 1990. Lutte raisonnée contre les mauvaises herbes dans les cultures de tomates d'industrie. Acta Hort. 277: 103-114.

Branthome, X. and Ple, Y., 1990. Intérêt et limites de l'utilisation des régulateurs de maturité. Acta Hort. 277: 69-75.

Bues, R., Toubon, J.F., and Poitout, H.S., 1985. Elaboration d'une lutte raisonnée contre les pucerons (*Macrosiphum euphorbiae* Thomas et *Mysus persicae* Sulzer) en cultures de tomates de conserve dans le sud-est de la France. Proc. workshop WPRS/OILB and EEC group on Integrated Plant Protection in field vegetables pp 15.

Bussières, Ph., 1990. Canevas de modèle d'une ligne de plantes de tomate semées explicitant sa variabilité spatiale. Acta Hort. 277: 221-227.

Caussanel, J.P., Abd el Fatah, H., Branthome, X., Maillet, J. and Jacquard, J. 1989. La concurrence morelle (*Solanum* sp.) * tomate (*Lycopersicon esculentum* Mill.) : résultats expérimentaux obtenus en France. EWRS, 4ème Symposium Méditerranéen de Malherbologie 2: 33-45.

Calado, A.M., Monzon, A., Clark, D.A., Phene, C.J., Ma, C., and Wang, Y., 1990 Monitoring and control of plant water stress in processing tomatoes. Acta Hort. 277: 129-136.

Calado, A.M., Portas, C.M., and Ferreira, A.G., 1990. Mobility of nitrogen, phosphorus and potassium in sandy soils in tomatoes for processing. Abstracts of contributed papers, 1. Oral, 1585. XXIII Int. Hort. Cong., Firenze (Italy).

Coltman, R.R., 1987. Sampling considerations for nitrate quick tests of greenhouse grown tomatoes. J. Amer. Soc. Hort. Sci. 112 (6): 922-927.

Damato, G. and Montemurro, P., 1986. Studio della competizione fra *Solanum nigrum* L. e pomodoro da industria trapianto. Difesa delle Piante 9 (4): 359-364.

Damidaux, R., Galvez, F. and Branthome, X., 1990. Comportement de lignées sauvages de tomate vis à vis d'herbicides efficaces sur *Solanum nigrum*. 14 ème Conf. du COLUMA, journées internationales d'études sur la lutte contre les mauvaises herbes, pp 7 (in press).

Dangler, J.M. and Locascio, S.J., 1990. External and internal blotchy ripening and fruit elemental content of trickle-irrigated tomatoes as affected by N and K application time. J. Amer. Soc. Hort. Sci. 115 (4): 547-549.

Dangler, J.M. and Locascio, S.J., 1990. Yield of trickle-irrigated tomatoes as affected by time of N and K application. J. Amer. Soc. Hort. Sci. 115 (4): 585-589.

Di Candilo, M. and Casarini, B., 1987. Pomodoro da industria : motivazioni e tecniche per la meccanizzazione della recolta. L'Inf. Agrar. 8: 29-69.

Dumas, Y., 1982. Variation de la hiérarchie des principales composantes de la fertilité en fonction des cultures. Cas des cultures légumières de plein champ en basse Vallée du Rhône. B.T.I., n° 370-372: 415-422.

Dumas, Y., 1989. Pour une fertilisation plus efficace et moins coûteuse : culture mécanisée de la tomate de conserve. P.H.M.-Rev. Hort. 294: 57-69.

Dumas, Y., 1990 a. Mechanization and input reduction in processing tomato cropping : agronomic aspects; building and testing of appropriate technical ways of management. Acta Hort. 277: 145-154.

Dumas, Y., 1990 b. Tomatoes for processing in 90's : nutrition and crop fertilization. Acta Hort. 277: 155-166.

Duranti, A. and Carone, F., 1983. Rapporti di competitività tra pomodoro seminato (*Lycopersicon esculentum* Mill. cv. "Petogro") ed infestanti. Rev. Ortofl. Ital. 67 (3): 191-207.

Freitas, M.B. de and Faria, C.M. de, 1981. Influência de práticas agrícolas na fertilidade do solo e no rendimento do tomateiro no agreste pernambucano. Revista Brasileira de Ciência do Solo 5 (1): 54-57.

Frost, D.J. and Kretchman, D.W., 1988. Plant spatial arrangement and density effects on small- and medium-vined processing tomatoes. J. Amer. Soc. Hort. Sci. 113 (1): 51-55.

Gerber, J., 1981. Direct seeding tomatoes : the future is here. American Vegetable Grower 29 (12): 6-7.

Grattan, S.R., Schwankl, L.J. and Lanini, W.T., 1988. Weed control by drip irrigation. Cal. Agr. 42 (3): 22-24.

Greenwood, D.J., Kubo, K., Burns, I.G. and Draycott, A., 1989. Apparent recovery of fertilizer N by vegetable crops. S. Sci. Pl. Nutr. 35 (3): 367-381.

Greig, J.K., Fogleman, M.E. and Wittsell, L.E., 1964. Soil compaction effects on transplanted tomatoes. J. Amer. Soc. Hort. Sci. 85: 490-496.

Grieshop, J.I., Zalom, F.G., and Miyao, G., 1988. Adoption and diffusion of integrated pest management innovations in agriculture. Bull. Entom. Soc. Am. 34 (2): 72-78.

Haigh, A.M. and Barlow, E.W.R., 1987. Germination and priming of tomato, carrot, onion, and sorghum seeds in a range of osmotica. J. Amer. Soc. Hort. Sci. 112 (2): 202-208.

Han, C.S., 1988. Comparison of irrigation schedules for processing tomatoes based on soil moisture measurement and climatological data. Acta Hort. 228: 91-96.

Huguet, J.G., 1985. Appréciation de l'état hydrique d'une plante à partir des variations micrométriques de la dimension des fruits ou des tiges au cours de la journée. Agronomie 5 (8): 733-741.

Labrada, R. and Perez, R., 1988. Medidas de lucha no química contra *Orobanche ramosa*. Agrotecnica de Cuba 20 (1): 35-40.

Lecocq, A. and Vayson, A, 1985. Les prévisions d'apports de tomate en usine. in Agrométéorologie et Productions légumières. Les Colloques de l'INRA. n° 33: 111-124.

Leskovar, D.I. and Sims, W.L., 1987. Emergence and yield of tomato (*Lycopersicon esculentum* Mill.) in response to presowing treatments. Acta Hort. 200: 145-152.

Locascio, S.J., Olson, S.M. and Rhoads, F.M., 1989. Water quantity and time of N and K application for trickle-irrigated tomatoes. J. Amer. Soc. Hort.Sci. 114 (2): 265-268.

May, D.M. and Valencia, J., 1990. Single versus double row spacing of six processing tomato cultivars. Acta Hort. 277: 97-102.

May, D.M., Wolcott, T., Peters, D., and Grimes, D.W., 1990. Moisture stress as it affects yields, soluble solids and viscosity of tomatoes. Acta Hort. 277: 123-128.

McKeowm, A.W., Cerkauskas, R.F., and Potter, J.W., 1988. Influence of strip tillage on yield, diseases, and nematodes of tomatoes. J. Amer. Soc. Hort. Sci. 113 (3): 328-331.

Mizrahi, Y., Taleisnik, E., Kagan-Zur, V., Zohzr, Y., Offenbach, R., Matan, E. and Golan, R., 1988. A saline irrigation regime for improving tomato fruit quality without reducing yield. J. Amer. Soc. Hort. Sci. 113 (2): 202-205.

Monaco, T.J., Grayson, A.S., and Sanders, D.C., 1981. Influence of four weed species on the growth, yield and quality of direct-seeded tomatoes. Weed Sci. 29 (4): 394-397.

Nichols, M.A., Nonnecke, I.L. and Phatak, S.C., 1973. Plant density studies with direct seeded tomatoes in Ontario, Canada. Sci. Hort. 1 (4): 309-320.

Osterli, P.P. and Meyer, J.L., 1977. Crop rotation improves nitrogen utilization. California Agriculture 31 (2): 7.

Phene, C.J., Davis, K.R., Hutmacher, R.B. and McCormick, R.L., 1987. Advantages of subsurface irrigation for processing tomatoes. Acta Hort. 200: 101-114.

Phene, C.J. and Clark, D.A., 1990. Real time irrigation scheduling with automated soil matric potential sensor measurements. Acta Hort. 278: 395-405.

Phene, C.J., Hutmacher, R.B., Davis, K.R. and McCormick, R.L., 1990. Water-fertilizer management of processing tomatoes. Acta Hort. 277: 137-143.

Portas, C.M., Branthome, X., Ple, Y. and Calado, A.M., 1990. Tomatoes for processing in the 90's : agricultural field practices. Acta Hort. 277: 83-96.

Puls, E.E. and Lambeth, V.N., 1974. Chemical stimulation of germination rate in aged tomato seeds. J. Amer. Soc. Hort. Sci. 99 (1): 9-12.

Putman, A.R., 1990. Vegetable weed control with minimal herbicide inputs. Hort Science 25 (2): 155-159.

Ruff,M.S., Krizek, D.T., Mirecki, R.M. and Inouye,D.W., 1987. Restricted root zone volume : influence on growth and development of tomato. J. Amer. Soc. Hort. Sci. 112 (5): 763-769.

Sanders, D.C., Howell, T.A., Hile, M.M.S., Hodges, L., Meek, D., and Phene, C.J., 1989. Yield and quality of processing tomatoes in response to irrigation rate and schedule. J. Amer. Soc. Hort. Sci. 114 (6): 904-908.

Siviero, P., 1990. Planification de la culture de la tomate en fonction de la récolte mécanique. Acta Hort. 277: 77-82.

Stoffella, P.J. and Maynard, D.N., 1988. Stand deficiencies and replanting effects on tomato fruit yields and size. J. Amer. Soc. Hort. Sci. 113 (5): 689-693.

Suniaga, J. and Dumas, Y., 1990. Mineral nutrition of tomato after germination. Influence of nitrogen on initial growth. Abstracts of contributed papers, 1. Oral, 1583. XXIII Int. Hort. Cong., Firenze (Italy).

Suniaga Quijada, J., 1990. Nutrition azotée de la tomate semée pendant la phase juvénile. Effets de différentes concentrations d'azote sur la croissance et le développement. Acta Hort. 277: 167-177.

Vergniaud, P., Maillet, J., Abd el Fatah, H., and Boneff, M., 1984. Influence des techniques culturales sur les peuplements d'adventices des cultures de tomate dans la basse vallée du Rhône. Proc. EWRS 3rd Symposium on Weed Problems in the Mediterranean Area 2: 381-388.

Wallace, A. and Abouzamzam, A.M., 1986. Interactions of soil conditioner with other limiting factors to achieve high crop yields. Soil Science 141 (5): 343-345.

Weaver, S.E., Smits, N. and Tan, C.S., 1987. Estimating yield losses of tomatoes (*Lycopersicon esculentum*) caused by nightshade (*Solanum* spp.) interferences. Weed Sci. 35 (2): 163-168.

Weaver, S.E. and Tan, C.S., 1987. Critical period of weed interference in field-seeded tomatoes and its relation to water stress and shading. Can. J. Pl. Sci. 67 (2): 575-583.

Widders, I.E. and Lorenz, O.A., 1979. Tomato root development as related to potassium nutrition. J. Amer. Soc. Hort. Sci. 104 (2): 216-220.

Wilson, L.T., Gutierrez, A.P., Tennyson, R., and Zalom, F.G., 1987. A physiological based model for processing tomato : crop and pest management. Acta Hort. 200: 125-132.

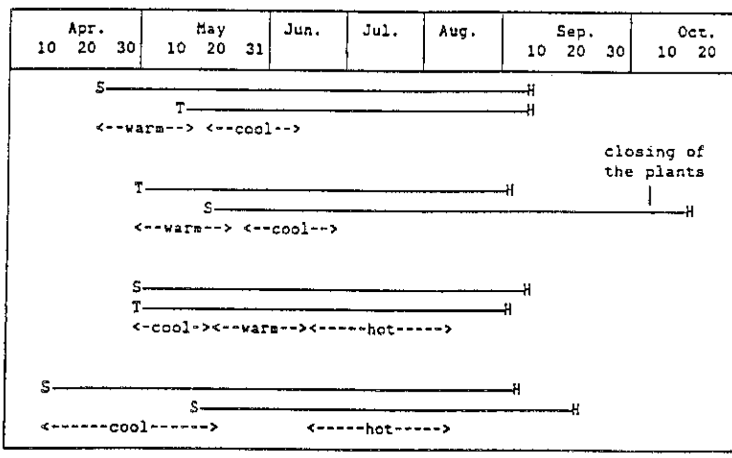
Wolf, S. and Rudich, J., 1988. The growth rates of fruits on different parts of the tomato plant and the effect of water stress on dry weight accumulation. Sci. Hort. 34 (1/2): 1-11.

Wolfe, D.W., 1990. The challenge : expanding the utilization of irrigation scheduling principles. Acta Hort. 278: 879-886.

Table 1. Compared changes in guaranteed minimum hour wage and the selling price of 1 Kg of tomato for paste in France.

	1978	1980	1982	1984	1986	1988	1990
A = Guaranteed minimum wage (FF)	10.85	14.00	19.64	23.84	26.92	28.76	31.28
Relative index	100	129	181	220	248	265	288
B = Tomato price (FF)	.41	.51	.61	.69	.66	.67	.70
Relative index	100	125	150	168	160	163	171
A/B	26.6	27.4	32.1	34.6	41.1	43.2	44.8
Relative index	100	103	121	130	155	162	169

Table 2. Crop planning and year to year climate variability: some schematic types of likely situations in the South-East of France.



S = seeding
T = transplanting
H = harvesting

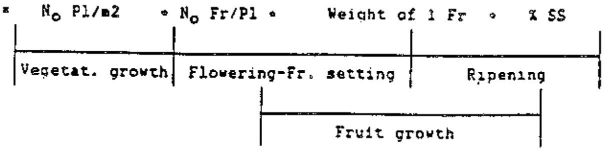
Table 3. Yield components (Y_Q = "quantitative" point of view; Y_q = "qualitative" point of view, e.g. soluble solids) and main development phases of determinate tomato for paste.

Y_Q (Kg Fr/m^2) = N_o of fruit/m^2 * Weight of 1 Fr

or

Y_Q (Kg Fr/m^2) = N_o Pl/m2 * N_o Fr/Pl * Weight of 1 Fr

Y_q (Kg SS/m^2) = N_o Pl/m2 * N_o Fr/Pl * Weight of 1 Fr * % SS



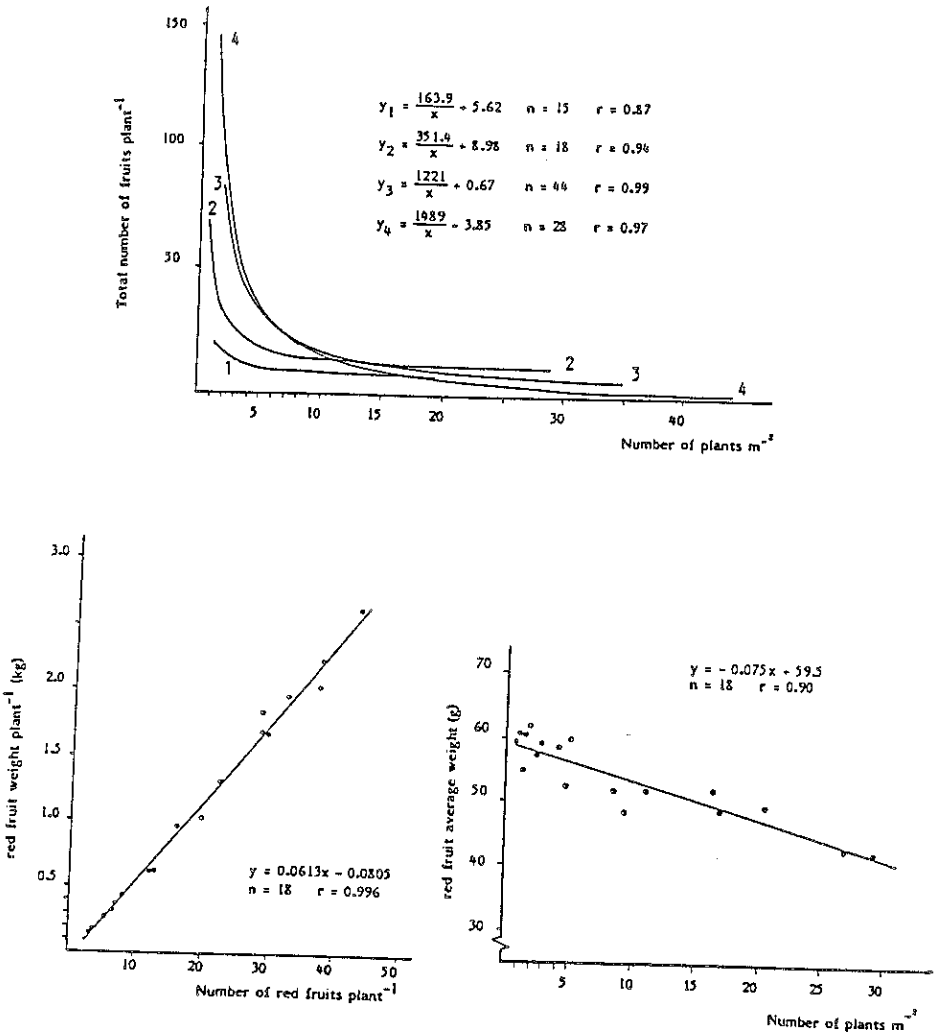


Figure 1. Influence of plant spacing on the tomato yield components in various situations of farm crops (cultivar UC 82) labelled 1, 2, 3 and 4. Density ranges were obtained by thinning stands emerged at a very high density in similarly managed fields on loamy clay soils.

Above : variability of stand responses to plant spacing.

Below on the left : number of red fruits plant^{-1} as the main yield component in crop 2.

Below on the right : individual fruit weight response to plant spacing in crop 2.

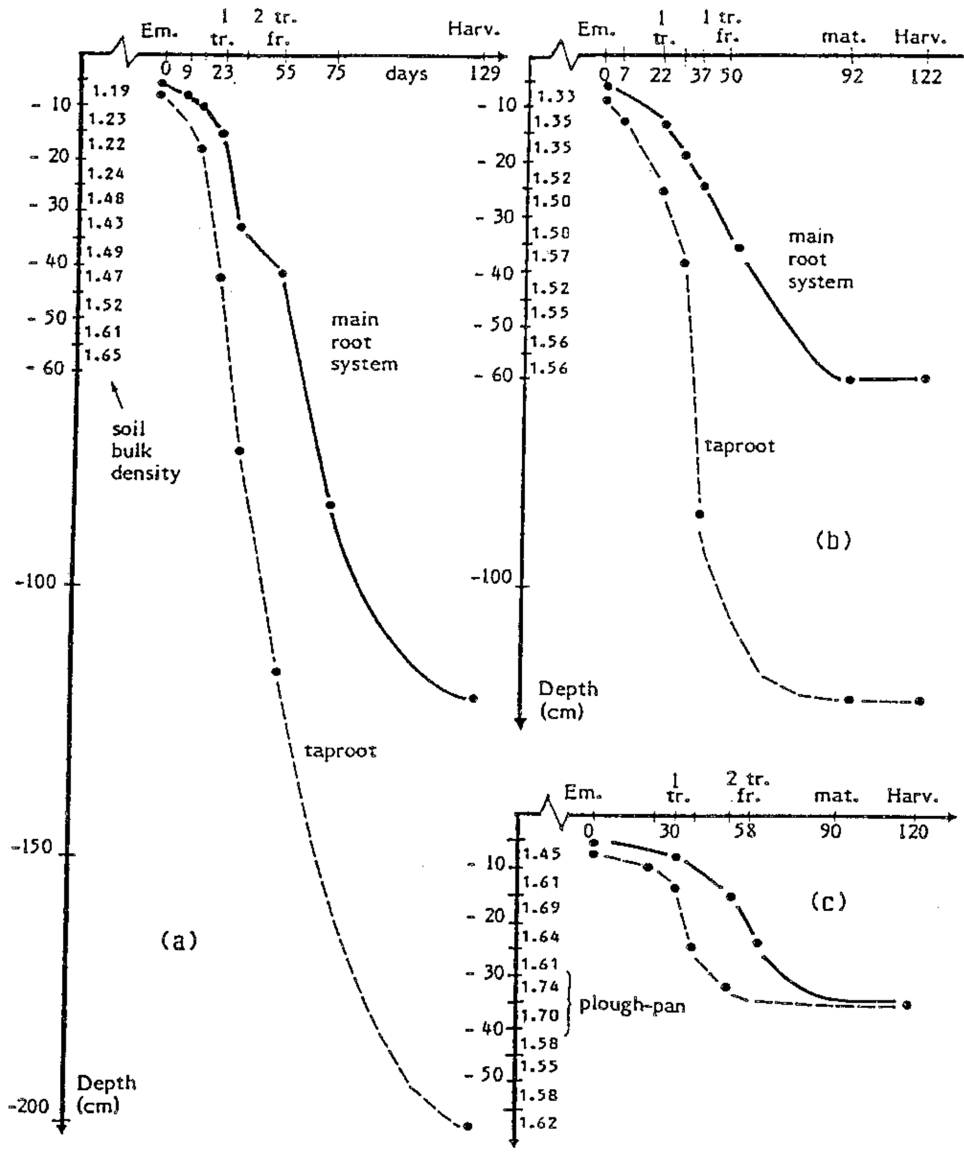


Figure 2. Influence of soil structure, particularly soil bulk density, on the depth of the tomato root system (cultivar UC 82) in loamy clay soils for three contemporary farm crops labelled (a), (b) and (c) (for comments see the text, section 3.1.3.).