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Improved agronomy and management of crop plants for industrial end uses

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1. General concepts

Agronomy, the science ruling the fields, has the privilege and the task of dealing with many aspects and related disciplines, covering the biological and the physical sphere. Harmonizing the complex of interactions arising form the organisms, factors and conditions involved in the process of plant growth is not an easy task, as general. Optimising plant growth and crop production, while safeguarding the environment, often proves a harder challenge. In this light, the crops for industrial end-uses may intrinsically be seen as crops of potential large scale, thus exerting a significant influence - both positive and negative – on the environment.

Crop management in its two aspects of quality and intensity is deeply involved in this influence, although the effects of crop inputs and techniques are seldom consistent, depending on the specific input, its level, the crop to which it is applied, other cropping conditions. The same is true for the long-studied influence of inputs/techniques on crop yield and quality. Yield and quality represent a good example of the problems to face, especially when they are adversely correlated, such as in the case of nitrogen fertilization in nitrogen-sensitive crops (e.g. sugar beet), requiring a compromise between contrasting effects; adding the environmental issue to the already-existing dualism of yield vs. quality, involves a higher-level

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compromise to be looked for, within what would otherwise be seen as “good” husbandry.

As to this, a common background linking most industrial crops is that, given the present financial context and the intrinsic nature of their products, they are grown in the effort to optimise the efficiency of all external inputs, such as fertilizers, irrigation, subsidiary energy spent in soil tillage, etc.. The process is susceptible of minimizing the load of chemicals on the environment, which is, in principle, a desirable outcome. On the other hand, the tendency to optimise inputs according to the expected response, disregarding the computation of mass balances, may trigger a progressive depletion of soil reserves, that is evident in the case of nutrients, but may extend to soil moisture, if a crop with a high ability to exploit soil water reserves is followed by another at lower aptitude, in the lack of restoring rainfalls. Referred to nutrients, this occurrence goes under the name of “soil mining” and represents a potential constraint to future production, which seems wiser to prevent than to recover from.

From the above discussion, it is perceived that the guidelines of agronomic improvement in crops for industrial end uses must follow a narrow pathway, in order to comply with opposite aims. In the specific of crop management, the operations that are needed to grow a crop may be grouped under a few basic categories: i) tillage/establishment of the crop, including seeding or transplanting of the breeding material; ii) nutrition, based on chemical and organic fertilization; iii) water management, covering both irrigation and adaptation to drought; iv) protection from competition and biotic stresses, i.e. weeds, pests and diseases; v) harvest/conditioning, which is the subject of closer relationship between agriculture and industry, focusing on harvest campaigns, product storage, supplying fluxes to industrial plants, etc..

Analysing the recent progress and the pending problems in each category, in the present agricultural context and with the available tools, seems the best way to outline a management for crops at industrial end uses.

2. Soil tillage and crop establishment

Soil tillage and crop establishment cover a vast array of interventions, ranging from none, in the case of already-established perennial crops, to a sequence of high intensiveness, e.g. in crops requiring a deep tillage, the preparation of a fine seedbed, and a low-speed seeding or transplanting.

2.1 Soil tillage

The modern approach in soil tillage is aimed at enhancing soil fertility, a task which is deeply embedded in traditional agronomy and does not represent, in itself, anything new.

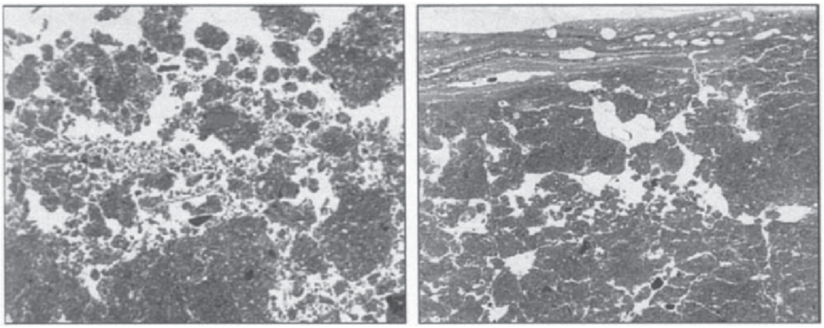

Fig. 4.1. Macro-photographs of vertically oriented thin sections prepared from undisturbed samples from the surface layer (0-100 mm) of soil tilled by continuous deep ploughing (left) and the same soil after raindrop impact (right). Surface crust formation is very evident. Frame length 35 mm x 28 mm. Reprinted from Soil Tillage Research, 79, Pagliai et al. Soil structure and the effect of management practices, 131-143, © 2004 Elsevier B.V., with permission from Elsevier.

Other tasks commonly associated with soil tillage, such as the incorporation of crop residues, fertilizers and weeds, are still performed, but alternatives are increasingly available, such as herbicides, fluid-fertilizer injection, crop-residue mulching, whose adoption deprives soil tillage of part of its former importance. Even within the vast issue of soil fertility, different concepts and purposes are now comprised with respect to the past. Chemical fertility, still a main issue in crop production, is a more appropriate concern of fertilization. Conversely, physical and biological fertility are the core of a modern policy of soil management, since the influence played by soil tillage cannot be easily replaced. Physical and biological fertility lie on the common principle that undisturbed soils are normally characterized by the best status. In agricultural soils, all the efforts are aimed at mimicking nature's action as much as possible, through tillage (Fig. 4.1). There is no single method corresponding to this concept, since the same results may be achieved through different ways. In other words, all the tools (inverting, non-inverting ones) and the techniques (deep, shallow, no tillage) are still valid and applicable, depending on specific aims and conditions.

In recent literature, the vast combination of tillage depths and instruments are investigated, in view of a sustainable crop production. Many parameters are analysed as potential soil-quality indicators. Among them, soil bulk density is considered a good indicator of soil structure, the high levels indicating compaction by heavy traffic and, to a lesser extent, by reconsolidation of the tilled layer (Botta et al. 2006; Hamilton-Manns et al. 2002).

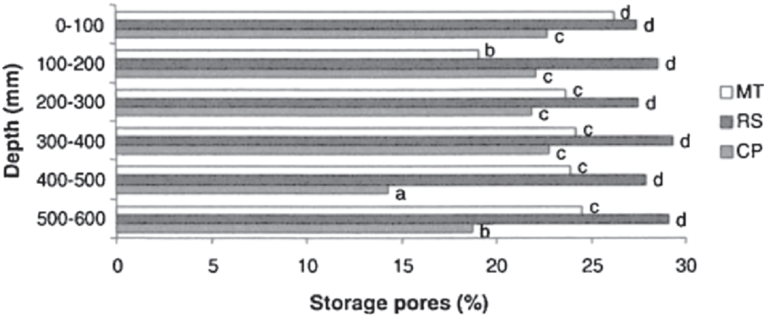

Fig. 4.2. Effect of tillage systems on elongated transmission pore distribution along soil profile expressed as a percentage of total area occupied by pores ranging from 50-500 μm per thin section (MT, minimum tillage; RS, ripper sub-soiling; CP, conventional deep ploughing). Values at each depth with different letters are significantly different at $P \leq 0.05$. Reprinted from Soil Tillage Research, 79, Pagliai et al. Soil structure and the effect of management practices, 131-143, © 2004 Elsevier B.V., with permission from Elsevier.

In this respect, no tillage and sod-seeding of the crop is responsible for higher bulk density in the top 0.08 to 0.15 m, compared to reduced and conventional tillage (Bescansa et al. 2006; Bhattacharyya et al. 2006; Singh and Malhi 2006; Dam et al. 2005; Deen and Kataki 2003). The result is an increase in soil strength, leading to a higher resistance to penetration, whereas water infiltration appears both positively (Liebig et al. 2004) and negatively (Singh and Malhi 2006) influenced by no-till. These effects generally end or reverse at deeper layers (> 0.15 m). In terms of bulk density and porosity, non-inverting, reduced tillage generally has an intermediate behaviour between ploughing and no tillage: in the case of ripper sub-soiling, a higher macro-porosity associated with a homogeneous distribution along soil profile has been observed (Pagliai et al. 2004), due to a larger number of elongated transmission pores, easing the passage of water through the profile (Fig. 4.2). The stability of soil aggregates to water is, consequently, improved, mitigating the tendency to soil crusting, an effect shown also for no tillage (Liebig et al. 2004). The resistance to wind erosion is improved by reduced and no tillage, too, thanks to larger aggregates, less sensitive to wind action (Malhi et al. 2006; Singh and Malhi 2006). So it is perceived that a reduced tillage intensity is possible or even beneficial to soil physical state and should, therefore, be economically pursued also in industrial crops. Examples are given for oilseed rape, which has achieved satisfactory yields in a review of the studies run in the Scandinavian countries on reduced tillage and direct drilling (Rasmussen 1999).

Table 4.1. Soil organic carbon sequestration rates (0-0.2 m soil depth) upon conversion from conventional tillage to no-till. Adapted from Agriculture, Ecosystems and Environment, 111, Tan and Lal, Carbon sequestration potential estimates with changes in land use and tillage practice in Ohio, USA, 140-152, © 2005 Elsevier B.V., with permission from Elsevier.

Location [a]	Duration year	Antecedent C content (g C m^{-2})	C change rate (g C m^{-2} yr^{-1})	
			Mean	Std dev.
Choshocton	17	924	47	9
Hoytville	16-19	589	50	36
Wooster	18-30	396	60	9
S. Charleston	18-28	266	87	50
Mean			62	29

[a] Several data sources and different soil taxa.

In sweet and fibre sorghum, the combined effect of shallow tillage (0.15 m) and low N and P fertilization (60 and 35 kg ha^{-1}, respectively), compared to conventional ploughing (0.3 m) and normal N and P rates (120 and 70 kg ha^{-1}, respectively), entailed a certain loss in biomass yield only in one year out of three (Amaducci et al. 2004), but the effect is not clearly attributable to soil tillage alone. Sunflower is another industrial crop investigated under different tillage, but the effects observed are more related to soil moisture as influenced by soil tillage, and later discussed, in the section on water management. In this crop, anyway, reduced tillage (chisel at 0.25-0.3 m) has been observed to limit early plant growth and N-uptake with respect to traditional one (ploughing), but not final seed yield and quality (Murillo et al. 1998); i.e. the more-compact crop maintained its yield potential, under relatively-dry conditions (Southern Spain).

The level of soil organic matter and the carbon-sink effect of soils are other important issues that may benefit from reduced tillage. No-tillage entails a lower mineralization of native organic matter and may contribute to a net CO_2 sequestration (Tan and Lal 2005) (Table 4.1), sometimes only in association with other factors such as stubble retention at the surface (Wang and Dalal 2005). The light fractions of organic matter and of N seem to be more involved in these increases, than the total amounts (Malhi et al. 2006). Also microbial-biomass and potentially mineralizable N, valuable indicators of soil quality, show higher levels in association with no tillage (Liebig et al. 2004; Salinas-García et al. 2002), at least in the surface layer: in fact, a soil-carbon stratification is clearly detectable in noninverting tillage compared to ploughing, depending on the stronger C sequestration operated by the former in the topsoil (Piovanelli et al. 2005). In this respect, minimum tillage may be seen as a good compromise between no-tillage and ploughing, in terms of organic matter content and distribution along the profile (Duiker and Beegle 2005; Deen and Kataki 2003). Even with the most conservative tillage systems, the balance in organic C may be negative with respect to former semi-natural systems. This is the case of an abandoned 15-year old grassland (Olson et al. 2005), where the loss in C after 12 years of cropping, still modest in no-till (10%), rose with chisel tillage (16%) and was further enhanced by mouldboard ploughing (27%). Seen from a different point of view, the difference of conservative tillage over conventional management represents a positive gain: in the cited research, the annual build-up of the C stock in the root zone (0-0.75 m depth) was set at 0.71 Mg ha^{-1} yr^{-1} for no tillage over ploughing, and at 0.46 for chisel tillage. In agreement, a simulation study showed an increase in the rate of soil carbon sequestration in the range of 0.4-0.8 Mg ha^{-1} yr^{-1}, depending on cropping system, with no-till management compared to conventional tillage (Thomson et al. 2006). At last, an experience on a single ploughing of a soil previously subjected to non-inverting tillage for 7-9 years (Koch and Stockfisch 2006), in order to overcome constraints of compaction, weed and slug infestation, resulted in a loss of organic matter of 6%, less severe than in Olson's et al. (2005) research, thanks to a less-conservative soil management maintained for a shorter time, but still showing the volatility of the benefits capitalized in years of conservation tillage, with the return of ploughing.

Worldwide, the steeply intensifying of agricultural practices in response to policy changes and fast population growth has resulted in an overall declines in soil C. For example, in temperate-zone agriculture, soil C was shown to decrease by 50% during the first 25 years of cultivation under intensive agricultural techniques (Matson et al. 1997). In developing countries, practice is to increase soil tillage, while reducing organic fertilizers and removing crop residues, thus resulting in lower levels of soil C and nutrients, thereby increasing fertilizer needs. For example, Metherell et al. (1995) demonstrated that soil C losses can be up to 50% lower for no-till compared to conventional tillage in a winter wheat-fallow rotation. Thus, while yield per unit area has steadily increased, yield per unit of fertilizer added has declined (Gale et al. 2002). China represents an emblematic example of this trend: the annual average cultivation-induced C losses have been estimated at 15 Mg (C) ha^{-1}, representing a total C-loss of 2 Pg C (Song et al. 2005). The IPCC (Intergovernmental Panel on Climate Change) Second Assessment Report has estimated that over the next 100 years it may be possible to restore two-third of carbon emission through sustainable agricultural practices such as reduced soil tillage and erosion control.

Table 4.2. Cropping system effect on soil organic carbon (SOC) and total nitrogen (TN) content, soil C:N ratio, and bulk density (BD) in the 0-0.15 and 0.15-0.30 m soil layer, after 10-year implementation of the cropping system experiment under no-tillage management. Adapted from Agriculture, Ecosystems and Environment, 105, Al-Kaisi et al. Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils, 635-647, © 2005 Elsevier B.V., with permission from Elsevier.

Cropping system	SOC ($Mg\ ha^{-1}$)		TN ($Mg\ ha^{-1}$)		C:N ratio		BD ($g\ cm^{-3}$)	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Smooth bromegrass	47,1 a	33,2 a	4,7 a	2,0 a	10,0 b	16,6 b	1,08 b	1,12 c
Switchgrass	40,7 a	26,3 a	2,4 b	0,8 b	17,0 a	32,9 a	1,25 a	1,17 b
Corn-soy-bean-alfalfa	26,7 b	17,0 b	2,1 b	0,8 b	12,7 b	21,3 b	1,27 a	1,29 a

Values in column with different letters are significantly different at $P \leq 0.05$.

It appears, then, as perennial crops have a competitive edge over annual ones in terms of carbon sequestration, and are to be preferred for this aspect, wherever a choice is possible within the same production chain, such as in the case of biomass crops for energy: switchgrass (*Panicum virgatum* L.) for instance, is a perennial grass of potential energy use, that was seen able to raise the soil-carbon content by an average 1.2 Mg ha^{-1} yr^{-1} over 10 years, compared to a typical rotation of temperate regions such as maize, soybean, alfalfa (Al-Kaisi et al. 2005) (Table 4.2).

Again, a five-year old switchgrass was shown to accumulate about 8 Mg ha^{-1} of dry roots, that is about five-times more than maize (Parrish et al. 1997). In the same crop, an increase of 2 g kg^{-1} of soil carbon was observed in just three years of cropping (Sanderson et al. 1997a), and, at five years from planting, about 25% of soil organic carbon originates from the crop (Garten and Wüllschleger 2000). Moreover, compared to traditional crops such as wheat and maize, switchgrass has been found to store the largest amount of C in a relatively-deep layer (0.3-0.9 m), less exposed to mineralization losses (Liebig et al. 2005; Frank et al. 2004).

From the discussed literature, it may be concluded that also industrial crops, despite their heterogeneity, should be able to play a positive role in the context of sustainability, by adopting methods of conservative tillage which, in turn, contribute to mitigate greenhouse gases emissions, to reduce soil erosion, and to improve the overall efficiency of the energy spent in cropping.

2.2 Crop planting

Crop planting is clearly linked to soil tillage. In the cropping systems at reduced or no-tillage, dedicated seeders have been developed, that are fitted with sturdier coulters or disks, in order to cut through superficial mulches (straw, stalks, desiccated weeds and cover crops) and place the seed at the right depth while improving soil-seed contact. The development of such machines is still in progress, focusing on specific parameters of seedbed quality, as it can be perceived from literature: in a recent research (Vamerali et al. 2006), for instance, a new kind of wide-sweep furrow opener compared with a traditional double-disc opener led to higher soil-residue mixing and lower bulk density in the top 0.05 m. These favourable conditions were, conversely, associated with a certain delay in maize emergence, which might be due to a lower soil/seed contact.

Rolling the seedbed to improve its firmness and the contact between soil and seed is often done in tillage systems, especially for small-seed crops. In one such industrial crop (switchgrass), rolling the seedbed prior to sowing, and in case also after sowing, has been shown to actually improve seedling emergence from 56% to an average 70% in a specific trial (Monti et al. 2001). This may lead to the false belief that a hard soil offers, by definition, favourable emergence conditions. The fact is proven wrong also in the cited experience, where the increase in soil resistance in the top 0.2 m, associated to no tillage, has been responsible for a substantial curb in emergence (Fig. 4.3), especially in the interval between 1 and 2 MPa. It appears, then, as a border should be erected between seedbed compression, a potentially-useful practice, and soil compaction, an unfavourable occurrence from all viewpoints.

The respect of proper seeding conditions also in simplified planting systems, as a premise to good crop stand and early growth, has been investigated in a trial where four different drill configuration were tried in no tillage on maize, wheat and soybean (Chen et al. 2004): removing the press wheel reduced the speed of emergence and the final population on normal and dry field conditions; removing also the gauge wheel resulted in double seeding depth on soft soil in laboratory conditions, leading to the same effects. Although a reduced and delayed emergence seldom affected yields in these trials, the importance of a complete, simultaneous establishment is implicitly supported.

As for transplanted crops, the preparation of the breeding material is a burden often puzzling farmers, that are accustomed to the simplicity of true seeds, or to well-organized supply chains, delivering them the seedlings at the right time and in the right shape (e.g. paper-pots) for their transplanters.

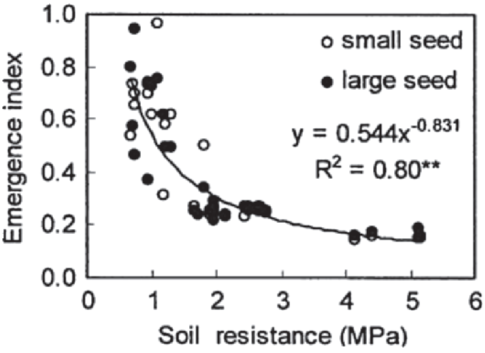

Fig. 4.3. Correlation between soil resistance at a 0-0.2 m depth and emergence index, the ratio of actual to potential seedlings, in small- and large-seed varieties of switchgrass. Reproduced from Soil & Tillage Research, 63, Monti et al. Evaluation of the establishment of lowland and upland switchgrass (*Panicum virgatum* L.) varieties under different tillage and seedbed conditions in northern Italy, 75-83, © 2001 Elsevier B.V., with permission from Elsevier.

For those crops that are normally planted through rhizomes, the preparation of a suitable number involves considerable amounts of time and labour and may, therefore, play a discriminating role against them. Other ways are, therefore, tried: in giant reed (*Arundo donax* L.), one such crop now susceptible of expansion as a biomass for energy in the frame of the Kyoto Protocol, the rush for of an adequate amount of breeding material is pressing towards simpler means than fractured rhizomes, such as stem cuttings placed into the soil with the generation of new plants from axillary buds (Gherbin et al. 2005), and is encouraging also micro-propagation trials.

2.3 Soil management during crop growth

In exchange for the potential complexity in the phases of soil preparation and crop planting, a few cares are generally needed along the cycle in modern industrial crops: over-seeding followed by thinning in the early stages is practically disappearing in the western world even in vegetables such as tomato. Inter-row hoeing is feasible in the crops having an interrow space wide enough (at least 0.4-0.5 m) to allow it. Its contribute to the control of weeds and, to a lesser extent, of soil evaporation is not negligible, especially in low-input cropping systems, where lower rates of herbicides, if any, are applicable. At last, earthing-up is limited to those crops taking advantage of the extra cover of soil on top of expanding tubers and rhizomes, or from the ridging of soil surface in view of furrow irrigation.

3. Crop nutrition

Crop nutrition is the base, along with light interception, of plant growth and crop production. The various micro- and macro-nutrients play different roles in the plant from a physiological point of view, that seem needless to discuss here. The crucial point is that the plant must be granted a balanced, satisfactory supply of all nutrients, in order to attain the desired growth, under non-limiting conditions of different nature (e.g. drought stress, pests and diseases, etc.). Assuring this condition while respecting other constraints, namely financial and environmental ones, is not an easy task. Mineral and organic fertilization are the tools to achieve the goal, but several other techniques must be considered, that interact with plant nutrition, both in a positive and in a negative way.

Industrial crops intrinsically have variable nutritional needs and responses to applied nutrients, depending on the species and on their destinations. So, a common picture of their behaviour may not be drawn, but a discussion of the concepts now prevailing in plant nutrition may help to better highlight modern trends in their fertilization.

3.1 Nitrogen

Nitrogen is the nutrient of greatest importance and of most delicate management throughout all crops. Apart from the leguminous species, that are little represented among industrial crops, plants mainly take up the nutrient from the pool of soil mineral N, which in turn is generally inadequate to satisfy their requirements, and must be fed by other sources, namely mineral and organic fertilizers. The problem is that nitrogen has a high mobility along soil profile, and may be leached in drainage water or volatilised to the atmosphere. More to that, the biological part of its cycle is not less complicate, since the relationships with soil biomass and specific bacteria are functional to the cycles of mineralization/immobilization that rule its availability.

Many decision-support systems are currently in use, in order to avoid the risk of nitrogen imbalances. The computation of nutrient budgets (balances), defined as the summary tables of nutrient inputs and outputs (Oenema 2003), may be considered one of the simplest: nutrient budgets may be set at three basic scales: soil system, soil surface (field) and farm gate. The system budget is, of course, specific of trial sites, although its results may be inferred into normal cropping situations, contributing data for useful considerations (Barbanti et al. 2006). The other two may be calculated with relative ease also for commercial crops/farms, although they are only approximate in the assessment of system imbalances: in fact, the application of the soil surface budget for nine years to a rotation including oilseed rape showed that only 13-25% of the surpluses originating from the computation were actually leached (Sieling and Kage 2006), indicating a poor correlation between anticipated and actual amounts.

More sophisticated systems are needed, in order to get more reliable outputs. To this aim, a more advanced approach is to implement actual soil nutrient status into the nutrient budget, as a specific reference. Many systems have been developed and validated, based on soil analysis; among them, one of the most diffused is the balance sheet, first developed in France (Rémy and Hébert 1977; Rémy and Viaux 1982). The principle is to take a representative soil sample at a significant depth (generally 0-0.9 m) and to determine mineral N, at the beginning or in early phases of crop cycle. Then other parameters are assumed, such as the expected mineralization during the cropping season, according to the soil type; the net mineralization/immobilization of organic fertilizers and of preceding crops' residues; the nutrient requirements at a standard (or personalized) yield potential, plus a small amount representing soil residual N-min at harvest. The algebraic sum of these items gives the amount of N to be applied as fertilizer. The method has been successfully in use for large-surface crops, primarily winter wheat and sugar beet. It has further evolved into a software (Machet et al. 1990), and is now implemented into a dynamic soil-crop model for winter wheat (Jeuffroy and Recous 1999) (Fig. 4.4), where it represents the soil sub-model, while the crop sub-model simulates growth and N-uptake according to the crop's simulated radiation use efficiency and to a critical dilution curve for nitrogen.

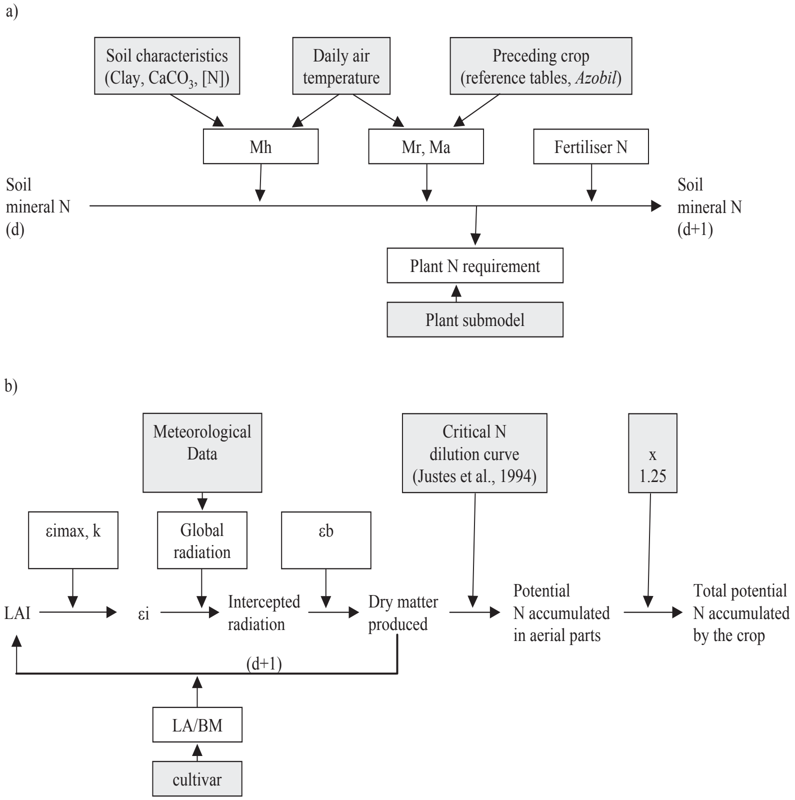

Fig. 4.4. Flow charts of the simulation model of daily soil nitrogen availability (a) and daily plant nitrogen requirements (b). Mh=net mineralization of humus; Mr=net mineralization of crop residues; Ma=net mineralization of organic wastes; εi=fraction of incident radiation intercepted by the crop; εb=radiation use efficiency; εimax and k=maximum εi and extinction coefficient; LA/BM=ratio of leaf area over total aerial biomass; boxes in grey=submodel input. Reproduced from European Journal of Agronomy, 10, Jeuffroy and Recous, Azodyn: a simple model simulating the date of nitrogen deficiency for decision support in wheat fertilization, 129-144, © 1999 Elsevier B.V., with permission from Elsevier.

Other methods have been developed, based on soil analysis of available forms of nitrogen with chemical (e.g., KCl, $CaCl_2$) and electro-chemical (EUF) extraction (Németh 1982; Wiklicky 1982), where the soil nutrient status is the base for the computation of fertilizer rates. None of them has been extended to industrial crops, although the adaptation of existing soil models should not be complicate, possibly requiring only the implementation of specific nitrogen uptakes, crop cycle and rooting depth.

Another large category of tools in nitrogen advising is that of plant indicators, instead of soil ones. Many chemical and optical assessments have been proposed: among them, the lab or field analysis of sap nitrate content in wheat stems and in sugar beet petioles; the rapid chlorophyll readings by means of dedicated tools (e.g. Minolta SPAD 502) based on optical absorbance (Yadava 1986); and the possibility of using ground-based measurements of spectral reflectance (Graeff and Claupein 2003).

Table 4.3. Summary of the main advantages and disadvantages of different sensing platforms. Adapted from Biosystems Engineering, 90, Scotford and Miller, Applications of spectral reflectance techniques in Northern European cereal production: a review, 235-250, © 2005 Elsevier B.V., with permission from Elsevier.

	Space	Aerial	Ground
Area covered per scan	Area scanned increases with platform height		
	typically km^2	typically m^2	typically cm^2
Spatial resolution	Resolution coarseness increases with platform height		
(pixel size)	1-30 m^2	0,05-2 m^2	mm^2 to cm^2
Temporal resolution	Weeks	days	hours
Affect of cloud cover	Influence of cloud increases with platform height		
	heavy influence	moderate infl.	not affected
Affect of local illumination conditions	Influence of illumin. conditions decreases with height		
	not affected	moderate infl.	heavy influence
Availability of data to end user	long delays	some delays	no delays
Control of end user	limited control	some control	full control

These systems are based on the principle of anticipating deficiencies through monitoring, in order to prevent them by fertilizing. They are very useful in horticultural crops, where drip irrigation allows a just-in-time delivery of fertilizers ("fertigation"); still of interest in the winter fertilization of wheat, but are unlikely to extend to crops whose management intrinsically requires simplification, such as many industrial crops.

More to that, their appeal in large-surface crops is rivalled by that of remote sensing, a term including both aerial (plane, helicopter) and space (satellite) sensing, based on spectral-reflectance analysis of crop images, although in a recent experiment (Reyniers et al. 2006) ground-based reflectance (CropScan multi-spectral radiometer) has proved more precise than aerial one (colour infra-red aerial image) in assessing wheat nutritional status and yield components at harvest. In a review (Scotford and Miller 2005), the advantages and disadvantages of the three sensing platforms, ground-, aerial- and space-based, are discussed and summarized (Table 4.3). It is concluded that, in order to provide quantitative crop information to aid input decisions, ground or aerial sensing are more appropriate than satellite one, because of higher spatial and temporal resolution. In another experience

(Jia et al. 2004), aerial true-colour photography has provided normalized colour intensities (red, green and blue bands) that were highly correlated with total N concentration, SPAD readings and sap nitrate in winter wheat, thus showing the possibility of replacing more-expensive terrestrial tools of nutrient assessment. Aerial sensing may, therefore, be seen as a good compromise between efficiency and accuracy, while satellite sensing is a field of promising development, given the commitment of private companies and public boards (e.g. the European Space Agency), but whose interest is presently restricted to simple applications of limited optical resolution, such as targeting crop inspections according to specific agricultural rules.

3.2 Other nutrients

The rest of macro-nutrients and all the micro-nutrients are of minor concern, compared to nitrogen. Yet, they deserve attention, since deficiencies are likely to impair plant growth and, consequently, affect crop yield.

As for the two other relevant macro-nutrients, P and K, sufficiency thresholds have been defined for common soil-crop combinations, using specific extractors. The management of P and K in fertilization has not substantially evolved recently: the two nutrients are either little mobile (K) or substantially static (P) in soil profile, so they need to be incorporated, if satisfactory concentrations are to be found at some depth from the surface. In this light, minimum and no tillage lead to a nutrient stratification, which can be partly overcome by application techniques such as soil injection or placement below the seed. Both recently proved an effective way of application in maize on K-deficient soils after twelve years of no tillage (Vyn et al. 2002). It is also argued that nutrient diagnostic methods should be adjusted to soil management, i.e. soil sampling should be maintained at a certain depth even in no-tillage, in order to have a good correlation between soil P status and wheat response to fertilizer (Zamuner et al. 2005), although another source (Duiker and Beegle 2005) suggests that samples in no tillage could potentially be taken at a shallower depth, provided that calibration curves are available. So there is no general agreement on the matter at present, probably because a bit too few experiences have been done so far. All the discussed concepts concerning P and K fertilization, described for cereals, are likely to apply also to industrial crops, which have been little investigated on this subject.

Likewise, also for secondary and micro-nutrients there is a scarcity of information on industrial crops. As a general, it is expected that industrial crops consist of vigorous plants, little affected by micro-deficiencies and other like constraints, but in fact this may not be stated for sure. The lack of literature supports this view, but the situation might change, especially for crops that are at the beginning of their diffusion. The only secondary nutrient that has been deeply investigated in the recent past is sulphur, which has showed a remarkable response to fertilization in cruciferous crops such as oilseed rape (Scherer 2001; Fismes et al. 2000), potential source of several industrial products.

3.3 Fertilizers

The type of fertilizer is of minor concern for industrial crops. Both mineral and organic fertilizers are suited to the needs of this large group of crops. Generally speaking, the financial context in which they are grown does not encourage the use of expensive nutrient sources. Therefore, sophisticated fertilizers such as the “nutritional specialties” proposed by many suppliers, featuring combinations of macro- and micro-nutrients, or nutrients plus bio-stimulators, or nitrogen forms at a delayed availability (slow-release, nitrification inhibitors, etc.), seldom pay off, despite the possibility of using less fertilizer units per hectare or reducing the number of split applications. The same circumstance affects, to a lesser extent, the use of complex fertilizers vs. simple (straight) ones. This is in accordance with the world trend in fertilizer types during the past thirty years, that has been strongly influenced by economics to the detriment of complex fertilizers, the group that had, in contrast, increased faster than simple fertilizers until the mid-seventies (IFA statistics).

One last remark concerns organic fertilization that are a valuable source of nutrients as well as of organic matter for agricultural soils that are, otherwise, increasingly depleted. More to that, they supply many secondary and micro-nutrients that are virtually absent in highly-concentrated synthetic fertilizers. But the remarkable aspect is that they allow a valorisation of waste products (livestock slurries, wastes of agro-industrial, urban or other origins), both composted or not, outside the food chain. This circumstance is less worrying for the fate of these wastes than in the case of food crops, associated with the intrinsic benefit of burying organic matter into the soil, thus contributing to soil carbon sequestration.

4. Water management

Water is a crucial biological factor. Of the word's available water resource, approx. 80% is currently consumed by irrigated agriculture (Condon et al. 2004) and 40% of the world food is produced in irrigated soil (Somerville and Briscoe 2001). Projected population growth indicates 9 billion people within 2050; as such this level of consumption is not sustainable in the future as more of the water resource is expected to be used for domestic, industrial, and municipal needs. In many areas of the world, water already is a scarce resource, with respect to potential consumptions. Other regions will likely add to the list in the future, given the present trend in world population and urban growth. Crops are, likewise, constrained by moisture deficiencies; in fact, there are a few agricultural areas where potential evapo-transpiration is met by natural supplies (precipitation, water table, inflows, etc.), whereas in the rest of them, a deficit occurs. Therefore, capturing all the available water and efficiently using it for vegetable production is a moral, if not a legal, obligation. Industrial crops are even more bound to this principle: since their principal products are not for food uses, they are susceptible to be passed over, in the allocation of limited water resources.

4.1 Coping with limited water resources

Three basic mechanisms of adaptation to drought stress are present in nature (Ludlow 1989): tolerance, involving the breeding of genotypes intrinsically characterized by a better resistance, i.e., capable of photosynthesising at lower leaf-water potentials; avoidance, reflecting the plant's attitude to face the stress (osmotic adjustment, stomata closure), until the adverse condition is relieved; escape, that is, completing plant growth before the onset of severe stress, or shifting crop cycle to a season in which the stress does not occur. The three mechanisms involve different possibilities of human intervention (breeding), such as improving transpiration efficiency, i.e. the acquisition of more C in exchange for water transpired; or partitioning more of the assimilated C into the end products. Other strategies may concern a better management of water resources and of environmental potential (escape), that are not easily or timely available in practice. All these strategies should not be seen singularly; rather, they would give the best results only with complementary approaches. The ways of improving crop water use pass through the reduction of losses from soil evaporation, deep drainage and runoff, three conditions often involving a major revision of the whole cropping system (Passioura 2006).

However, the major breakthroughs in improving crop performances under dry conditions are expected from breeding. In fact, the prospects for increasing water use efficiency by improving photosynthetic efficiency at a leaf-scale are estimated greater than those for increasing the efficiency of light interception or of biomass partitioning to commercial organs, which have been widely exploited in the past. The overall breeding potential to increase photosynthetic efficiency is estimated at approx. 50%, a very high score in genetic terms (Long et al. 2006).

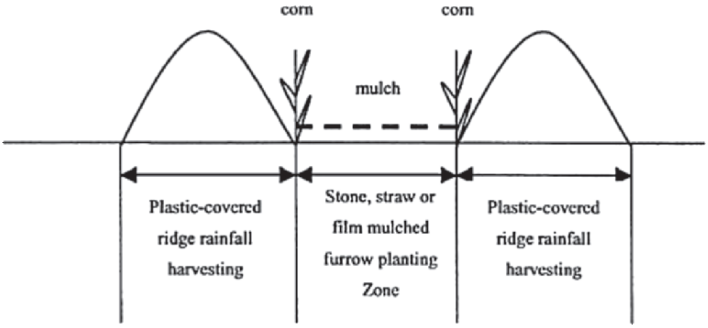

Fig. 4.5. A schematic diagram showing ridge and furrow rainfall harvesting system with mulches. Reproduced from Agricultural Water Management, 54, Li and Gong, Effects of different ridge to furrow ratios and supplemental irrigation on crop production in ridge and furrow rainfall harvesting system with mulches, 243-254, © 2002 Elsevier B.V., with permission from Elsevier.

Another possibility of increasing water availability for crops is rainfall harvesting: shaping the soil surface in ridge and furrows concentrates moisture (Fig. 4.5). In an arid region of inner China, the combination of plastic-covered ridges and mulched furrows has been capable of increasing maize yield by 60-95% in drought and average years; 70-90% in wet years and 20-30% in very wet years (Li et al. 2001), with the largest single contribution coming from the plastic cover than from the simple ridging of the soil or from the furrow mulching. Different ridge-to-furrow ratios have also been tested (Li and Gong 2002), showing an inverse relationship between average yearly precipitation and optimal value of the ratio, i.e. the driest the conditions, the largest the surface needed for water harvesting. In both experiences, water use efficiency (WUE), the parameter expressing the unit of dry biomass or commercial product per unit of water (e.g. kg m^{-3}), significantly increased with rainfall harvesting, and also supplemental irrigation, in addition to water harvesting, brought about an increase of maize yield and WUE. Therefore, the cited researches show that water harvesting not only made more water available for the crop, but enhanced its efficiency.

In contrast to this, another experience on sunflower shows that increasing soil water content at seeding through fallow management may not systematically be the best option (Aboudrare et al. 2006).

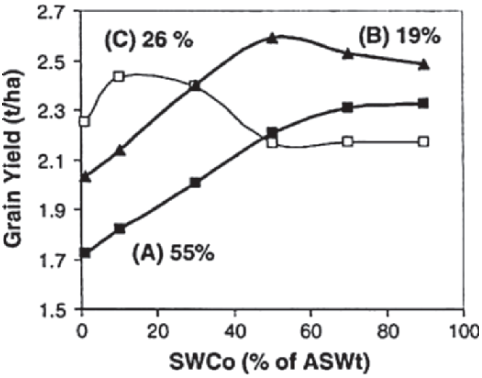

Fig. 4.6. Three types of yield response to initial soil water content (SWCo), as fraction of total available water (ASWt): simulation with EPIC-Phase (1960–1998). For each type, percent frequencies are indicated. Reproduced from Agricultural Water Management in press, Aboudrare et al. Effects of soil tillage and fallow management on soil water storage and sunflower production in a semi-arid Mediterranean climate, 1-14, © 2005 Elsevier B.V., with permission from Elsevier.

In this experience, chisel tillage proved the best compromise, within different tools and techniques, for optimising water storage in clayey soils of Morocco, among years at different amount and distribution of rains during the autumn-winter. But a high soil water reserve at seeding leads to an excessive leaf canopy at the bud stage, which in turn more rapidly depletes water and negatively affects yield and WUE, especially in a dry growing season. A partial restoration of the soil water reserve at seeding ensures, in comparison, steadier yields, as shown by a simulation run over the years, where a cumulated frequency of 45% of maximum yields is achieved with an initial moisture not exceeding 50% of total available water (Fig. 4.6).

So, the direct harvesting of water and the indirect techniques to store it may have contrasting effects, which need to be carefully evaluated before setting out for any programme. In the case of water harvesting, a considerable drawback is represented by the large request of labour for carrying it out, although in developing countries the system is worth consideration, if it is deemed capable of supporting yields.

4.2 Irrigation

The supply of water is basically conditioned by its availability at the needed time, and by the economic convenience in using it. The latter, in turn, depends on the cost of water and of its application, on crop physical responsiveness to irrigation and on crop selling price. It is easily understood that any failure in the chain of supply/valorisation of water undermines the financial return of irrigation.

Water use efficiencies of either the total amount consumed by the crop (WUE) or that supplied through irrigation (IWUE), are good estimates of crop overall efficiency and responsiveness to irrigation, respectively. Irrigation is susceptible of enhancing growth, raising yields, often at the expenses of WUE. Therefore, the conditions must be sought, in which this circumstance takes place to the least extent. Deficit irrigation, a supply of water that is only a fraction of the evapo-transpiration deficit, may improve yield and also WUE, especially if applied in critical phases of crops growing in severe water stress (Xue et al. 2006; Tavakkoli and Oweis 2004). Since in dry areas the rotation is often reduced to the fittest crops, which in many cases means a monoculture of winter wheat, widening the rotation may improve WUE, along with the duration of crop coverage during the rainy season and the amount of rain intercepted by crops (Huang et al. 2003).

In grain sorghum, IWUE has been shown to decline at increasing irrigation volumes in lysimeter studies (Tolk and Howell 2003), whereas trials in the open field have showed an opposite trend (Farré and Faci 2006). Grain sorghum has often proved a good alternative to maize in water-limiting environments, thanks to higher WUE and IWUE, harvest index, soil-moisture depleting potential (Farré and Faci 2006) (Fig. 4.7), and water-table exploitation (Sepaskhah et al. 2003). Grain sorghum is also a potential energy crop, but more-dedicated ones are sweet and fibre sorghum, of the same species as the grain type (*Sorghum bicolor* (L.) Moench), but at high vegetative growth and comparably-lower grain yield. In Southern Italy (Mastrorilli et al. 1999), sweet sorghum has proven more sensitive to early water stress, during the early ("leafy") stages of plant growth, than in the later ("stem") stages: over three years, the early, temporary stress significantly affected growth, final yield (-34% dry biomass than the well-watered control) and WUE (-17%), whereas the late stress, at a comparable water consumption, brought about lower, insignificant variations: -11% in yield and +6% in WUE. In the wetter environment of Northern Italy (Amaducci et al. 2000), fibre sorghum did not take advantage of irrigation, although it was by far the highest-yielding crop among three other fibre crops (hemp, kenaf, fibre maize), whose two (kenaf and fibre maize) were significantly enhanced by irrigation. The insignificant and positive effects of irrigation on the dry matter yield of, respectively, fibre sorghum and kenaf were also confirmed by other experiences in sandy soils under similar wet conditions (Monti et al. 2002).

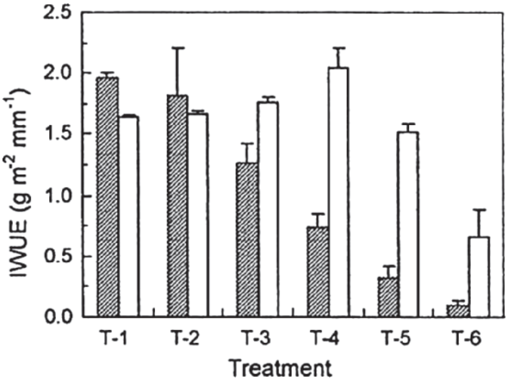

Fig. 4.7. Irrigation water use efficiency (IWUE), expressed as the ratio of grain yield to seasonal irrigation applied, for the different irrigation treatments in maize (full bars) and sorghum (empty bars). Bars represent standard errors. T-1 to T-6 represent decreasing irrigation treatments. Reproduced from Agricultural Water Management in press, Farré and Faci, Comparative response of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) to deficit irrigation in a Mediterranean environment, 1-9, © 2005 Elsevier B.V., with permission from Elsevier.

Both sweet sorghum with late water deficit in the former research (Mastrorilli et al. 1999) and the rainfed fibre type in the latter ones (Monti et al. 2002; Amaducci et al. 2000) attained average dry-matter yields of 26-28 Mg ha^{-1} in trail plots, associated, in the previous research, with a WUE of about 6 g kg^{-1}. The combination of the two figures well describes the species' remarkable potential.

Miscanthus (*Miscanthus x giganteus* Gref et Deu) is another biomass crop investigated under irrigation. Miscanthus is a C_4 grass like sorghum, but is a rhizomatous perennial. In a Mediterranean environment of Central Italy, irrigation showed a positive interaction with N fertilization (Ercoli et al. 1999): in fact, at no nitrogen supply, irrigation did not raise biomass yield, which was, conversely, enhanced at full N rate (200 kg ha^{-1}). The positive interaction between nitrogen and irrigation almost doubled net energy yield (output – input), given that the calorific value was uninfluenced by the two factors. In contrast, energy efficiency (output/input) was more than halved in the rainfed crop by the input of nitrogen, and significantly fell also in the irrigated crop. The positive effect of irrigation on dry matter yield of miscanthus was also ascertained in North Italy under a wetter conditions, yet no significant interaction with nitrogen dose was observed in this case (Monti et al. 2002). In a pot experiment, three Miscanthus species were compared under water stress, in order to investigate WUE and biomass partitioning (Clifton-Brown and Lewandowski 2000). A *M. sinensis* hybrid offered a better resistance to leaf senescence than *M.* x *giganteus* and *M. sacchariflorus*, thanks to a reduced leaf conductance. Because of that, WUE on the total biomass did not significantly vary among the three genotypes, whereas WUE on the stem component showed differences in dry matter partitioning, to the advantage of *M. sacchariflorus* over the other two genotypes.

A non-gramineous industrial crop widely investigated as it concerns water relations is sunflower. The crop is a profligate water user (Connor and Sadras 1992), although it has a deep rooting and a good ability to tap on ground water. It is most drought-sensitive at the beginning of the reproductive stages, which is confirmed by a recent research in a Mediterranean environment (Göksoy et al. 2004): irrigating only at flowering showed by far the highest IWUE, compared to irrigating at heading, milking and at various combinations of the three stages. A more-intensive irrigation programme further enhanced seed yield, at the expenses of high amounts of water. In another experience in a semi-arid environment (Gajri et al. 1997), deep tillage (0.4 m) and/or mulching helped the crop in efficiently using soil water, which pressed irrigation to show a stronger response in conventional tillage (0.1 m depth). The crop appears, anyway, not suited for very dry soils and climate, since the volumes needed to optimise yield (350-800 mm) seem too high for an economic use of water.

The application of crop simulation models to sunflower (Rinaldi 2001; Rinaldi et al. 2003) once more showed that the highest economic return is attained by deficit irrigation, involving either irrigating (200 L m^{-2}) only at bud flower stage (EPIC model), or irrigating whenever soil water content passed below 40% of total soil water capacity (OLICROP-SUN model).

Irrigation and advanced seeding influenced also fatty acid composition of high-oleic sunflower, with a decrease in oleic and an increase in linoleic acid, an unfavourable combination likely due to the effect of lower temperatures in the early phases of seed development, enhancing the enzymatic transformation of the former into the latter (Flagella et al. 2002).

Irrigation was also found to consistently increase the above-ground structural parts in the two inulin crops chicory and Jerusalem artichoke (Monti et al. 2005 a, b; Schittenhelm 1999). However, dry biomass accumulation did not run in parallel to the fructan storage. The only significant effect of water regime was to speed up the accumulation of fructan in chicory, and to delay the tuber formation and degree of polymerisation in

Jerusalem artichoke, probably related to the sink-to-source ratio (Monti et al. 2005a; b).

4.3 Irrigation management on a large scale

A few words need to be spent on the management of irrigation at the district/basin level, implying an articulate reasoning on crop needs, water availability, and other related issues. Simulation models and remote sensing play an important role in the subject.

The first step is the assessment of water needs, i.e., the imbalance between precipitation and crop evapo-transpiration (ET). The possibility of determining ET fluxes through satellite sensing of canopy biophysical properties, integrated by agro-meteorological information, has been successfully proved in a very homogeneous district (Consoli et al. 2006), but the same result would be less-easily achieved in areas characterized by a mixed agricultural landscape. In such areas, reference ET, simulated by several equations or methods, should be the base for assumptions and adaptations in order to better fit the data to the territory.

The second, capital step is the management of water resources. To this aim, geographical information systems (GIS) are widely employed, in association with crop modelling. An example of a good integration of the two tools in the frame of best management practices for irrigation and nitrogen fertilization, applying multi-criteria analysis to a set of agro-environmental indicators, showed that water-flow control was the critical point for reducing pollution in a drainage basin of Northern Italy. Controlling it through a better irrigation tuning enabled significant reductions in nitrogen leaching, while improving crop yields (Morari et al. 2004). Other GIS applications are aimed at supporting the implementation of improved farm irrigation management, as related to water saving and salinity control (Fortes et al. 2005), and for the development of irrigation scenarios at different scales, according to spatial variation, climatic and management conditions (Todorovic and Steduto 2003).

The remote control of large irrigation networks is a rising possibility with WLAN (wireless local area network) technology, associated to solar panels to power the system. In one such example (Damas et al. 2001), the division of a 1500-ha area into seven sub-regions, monitored and controlled by inter-communicating sectors subjected to a central unit, enabled programming/carrying out of the irrigation shifts, controlling pumps/valves works and reservoir levels, while claiming a significant (30-60%) possibility of water saving.

The last capital issue at basin level is the allocation of water for irrigation vs. other uses. The problem, as Lankford (2004) observed, is that the irrigation designs laid out without sufficiently accounting for alternative uses of water in semi-arid environments, tend to over-prioritise water for irrigation systems ("irrigation centred"), at the expenses of re-allocation to other uses. Focusing, instead, on the river basin in a "water-resource-centred" approach, is argued to better comply with the multiple interests involved in the use of water.

A similar idea is echoed by Rosenzweig et al. (2004), who analysed the implications of changes in crop water demand and water availability for the reliability of irrigation systems, by linking climate change scenarios with hydrologic, agricultural and planning models, in five major agricultural regions around the world. The simulation showed that only one study area (Brazil) can readily accommodate an expansion of irrigated land under climate change; three others (Northern Argentina, the Danube Basin and the US) would suffer decreases in the reliability of irrigation; the last case, Northern China, already experiences a serious lack of water at present. It is, therefore, concluded that even in the relatively water-rich areas, changes in water demand due to the climate and to increased demand from urban growth will require timely improvements in crop cultivars and water management, in order to comply with the projected scenarios.

5. Crop protection

Crop protection from the competition of weeds and from the biotic stresses caused by pests and diseases is too vast a subject to be acceptably discussed in a limited space, since a few guidelines may be found in the huge combination of crops per weeds, pests and diseases. Nevertheless, some trends and common behaviours may be outlined, in tackling these problems in a modern crop management.

It is almost needless to repeat that industrial crops have to be cheap in cropping and efficient in the use of inputs, above all in the conversion of energy. More to that, the sensorial quality of their products, meant as agricultural raw materials, is of the least importance. It follows that only the biotic stresses/competitions that are seriously threatening yield or industrial quality should be taken into consideration within a programme of crop protection.

5.1 Assessing the damage

A brief outlook on the subject may begin with the assessment of the yield-loss potential (no-control scenario) compared to the actual loss, in some prominent arable crops (four cereals, soybean, sugar beet, potato and cotton) in seventeen agricultural regions around the world (Oerke and Dehne 2004). The loss potential varies from less than 50% (barley) to more than 80% (sugar beet, cotton). The actual loss, given the control measures normally deployed, is consistently lower and unrelated to potential loss; it varies from 25-30% of sugar beet, barley, soybean, wheat and cotton, to 35-40% of maize, potato and rice. The efficacy of crop protection (mechanical, physical, chemical means) is, therefore, higher and more consistent in cash crops (sugar beet, cotton), whose relevant loss potential is quite well controlled (60%) by a more intensive protection programme; conversely, the efficacy is modest and more fluctuating in the rest of the crops (average 46%), where a lower loss potential is associated with tighter profits, hampering the implementation of a better strategy. Among the sources of yield loss, weeds have the highest potential (32%), followed by animal pests and pathogens (18% and 15%, respectively) and by viruses (1-3%); but since weeds can be controlled through mechanical or chemical means, average efficacy in weed control (68%) is considerably higher than that in pest and disease controls (39% and 32%, respectively), which rely more heavily on pesticides.

In this picture, industrial crops are not included, apart from cotton. It may be sensed, anyway, that their global behaviour should resemble that of cereals, themselves being grown for industrial end uses, sometimes. In other words, the group is globally expected to behave like crops less-severely impaired by the complex of pests, diseases and weeds, but at the same time less prone to efficient control measures. The reasons are the intrinsic financial constraints, but also a lower number of registered active ingredients, and a frequent lack of information on pest-and-disease epidemics in these specific crops.

5.2 Integrated crop protection

Given these limitations, an integrated approach to crop protection, combining chemical active ingredients with agronomic and genetic tools, is the one that best fits the majority of industrial crops. This same approach is widely followed in food crops, too, where a reduction in the use of pesticides is equally sought. The critical point of its implementation is acknowledging the role of the agronomic factors, in order to harmonize them towards the desired aim. Therefore, the recognition of the effects carried out by agronomic practices, especially in the area of crop rotation and soil tillage, is the key to a successful exploitation.

Examples of such effects and of the subtle mechanisms involved are offered by Meynard et al. (2003), who showed how cropping systems in the case of winter wheat have a large effect on the size of the primary inoculum of eyespot (*Pseudocercosporella herpothricoides*) and on its localisation at the soil surface, directly related to the extent of disease symptoms: keeping the residues of a previous wheat crop as far from the surface as allowed by crop sequence and soil tillage, helps to significantly reduce the attack, whereas a careless management, e.g. ploughing twice since the previous wheat crops, brings more inoculum to the surface and enhances disease severity. Other effects, still reported by Meynard et al. (2003), concern: the development and spread of epidemics, with an example of the slowing of grey mould of vines (*Botrytis cinerea*) thanks to several indirect practices in vineyard management; the coordination of the life cycle of cultivated plants and related parasites, showing both positive (oilseed rape) and negative (wheat) effects resulting from advanced seeding, depending on the specific, respective parasite (black leg and eyespot) and on the associated time of contamination (spring and autumn, respectively); at last, the disrupted ecological equilibrium within soil microflora, either favouring or disfavouring the pathogens, in a complex study case on take-all of wheat (*Gaeumannomyces graminis*) in various patterns of set-aside management.

Other examples may be found in literature, but the point is that the cumulated experiences on the combinations of single pests (diseases, weeds) and crops should be sufficiently advanced for the build-up of decision support tools for a better design of cropping systems, a circumstance that is now achieved only for a few adversities in a limited number of crops; in fact, the crop-protection support systems currently in use are more focused on the use of existing pesticides, than on integrated protection management (Murali et al. 1999). In the rest of cases, the maturated experiences on synergies/antagonisms and the general knowledge of basic agronomic effects may be played within the farmer's sensitivity and habits. The fact enhances personal abilities but undermines the possibility of a consistent support to cropping choices, which reflects on the quality of cropping and, eventually, on the consistency of yields.

5.3 The contribution from breeding

The contribution of breeding to weed control and crop protection, including GM crops, is not negligible, although it may only be hinted at, in the present outlook. The resistance to pathogens is a constant effort in many breeding programmes: improved varieties are continuously being released with strengthened characters of resistance to specific parasites. Examples are present also in industrial crops, such as in sunflower, with the added resistance to powdery mildew in existing hybrids, significantly reducing disease symptoms (Laureti et al. 2006).

Genetic modifications are a powerful tool in the farmer's hands to cope with biotic adversities. Some industrial crops already display genetically-modified varieties, in the frame of resistance to non-selective herbicides (e.g. oilseed rape) and to insect pests (e.g. cotton). The much-debated worldwide acceptance of GM crops is somehow slowing their progress, but other constraints need not be forgotten, such as the fact that crops of limited worldwide diffusion are not likely to be ever subjected to these transformations, and that the use of GM crops, such as the herbicide-resistant ones, raises concern not only among environmentalists, but also for some agronomic drawbacks, such as the strong selective pressure imposed on weed flora, possibly enabling it to overcome herbicide control.

With this remark, GM crops as well as traditional genetic resistance are to be viewed as complementary tools in crop protection, not as the ultimate remedy to plant biotic adversities.

6. Precision agriculture

Precision agriculture is a subject of increasing interest, encompassing all the previously-discussed categories of crop management. It is seen as the new frontier of agronomy by some scientists; others more realistically view it as a tool susceptible of improving the ways of tackling existing problems.

The concept of precision agriculture lies on the technology of the global positioning system (GPS), a method for soil-surface locating through satellite sensing, with a remarkable accuracy (0.05-0.1 m). GPS-provided harvesters equipped with on-the-go yield monitoring produce yield maps, showing the extent and the pattern of yield variation within the field. Once reasons have been identified for the differences in yield, site-specific application of nutrients, active ingredients, seeding, water and tillage (Fig. 4.8) can help to overcome the problems or to cope with them, while at the same time avoiding the contradiction of uniform treatments applied to variable soil conditions.

This is in principle; in practice the problem is that, since the act of yield mapping, it is quite easy to incur in errors, miscalculations, etc., leading to incorrect assumptions for the decision to be taken. More to that, a whole generation of sensors is needed for both yield-monitoring at harvest, and continuous sensing of soil/crop properties during crop cycle, that are still being evaluated and improved, according to the evolution of technology and to the results in field tests.

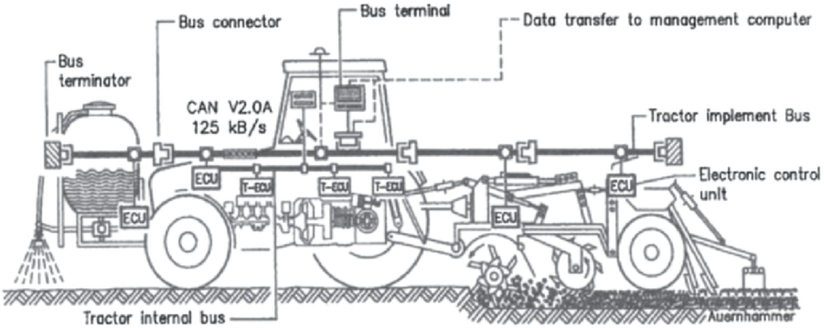

Fig. 4.8. The ‘Landwirtschaftliches BUS-System (LBS)’, an example of communicating outfit between tractor, equipment and farm-management system, catering to the needs of small-scale European farmers. Reproduced from Computers and Electronics in Agriculture, 30, Auernhammer, Precision farming - the environmental challenge, 31-43, © 2001 Elsevier B.V., with permission from Elsevier.

The combined complexity on these two sides of monitoring, associated to the field size, to the cost of instruments, and to the overlapping and sometimes prevailing effects of unpredictable climatic conditions on yield, considerably slows the progress of precision agriculture. A short review of the recent literature may, as in other cases, reveal pending problems and highlight current trends, seen in the perspective of industrial crops.

6.1 Yield mapping

The problem of dealing with the errors in yield maps has been recently investigated by Robinson and Metternicht (2005), who managed to rectify them. In their research on winter wheat in Australia, all the sources of error (unknown harvest width, time-lag in grain-yield sensing, inappropriate GPS recording, yield surges, and other outlying values) made up 17% of the total data-set acquired on a 96-hectare surface; its elimination resulted in a substantial reduction in the amount of uncertainty. The accuracy of spatial-interpolation techniques was assessed over the whole surface by minimizing the differences between true and interpolated values (Root Mean Square Error parameter), although it was argued that the resulting map of the area, used to assist in future crop management, should not be based only on RMSE values, but also on the degree of smoothing and data aggregation that is desirable and allowable by the filtered data-set.

Yield maps are also the subject of hot debate and criticism. Assumptions based on winter-cereal yields, for instance, do not easily apply to crops of different family, cycle, habit, like sugar beet (Jaggard et al. 2000). In quite-uniform cropping systems, such as in cereal-dominated rotations, there is compensation in the spatial distribution of crop yields over the years, so that the spatial variation reduces with time (Godwin et al. 2003). Even so, anyway, maps of previous crops' yields did not prove a useful basis for assessing a strategy of variable nitrogen rates in the cited experience, compared to aerial photography of the crop in the actual growth conditions.

The problem of the yields recorded on the same field from different crops succeeding in time does not apply to perennial crops. In such case, maps may highlight soil physical and chemical characteristics associated with yield (Di Virgilio et al. 2006), whose some are susceptible of being improved during the years, to the benefit of cumulated yield.

This case, anyway, confirms the role of yield maps as more suited for directing soil sampling to identify potential constraints, than for a direct strategy of input-adjustment in the following crop.

6.2 Real-time monitoring

The second category of monitoring, devoted to "real-time" sensing and decision-making, is a more promising field of interest, as a larger number of scientific references testifies. The tools and the technologies employed in this direct probing of soil or crop properties are the core of the problem.

6.2.1 Soil sensing

Adamchuk et al. (2004) recently reviewed on-the-go soil sensors, grouping them in six categories: i) electrical and electromagnetic sensors, measuring electrical resistivity/conductivity, capacitance or inductance as affected by soil composition; ii) optical and radiometric sensors, using electromagnetic waves to detect the level of energy absorbed/reflected by soil particles; iii) mechanical sensors, measuring forces resulting from a tool engaged with the soil; iv) acoustic sensors, quantifying the sound produced by a tool interacting with the soil; v) pneumatic sensors, assessing the ability to inject air into the soil; vi) electrochemical sensors, using ion-selective electrodes and transistors that produce a voltage output according to selected ions (H^+, K^+, NO_3^-, Na^+, etc.). Different soil properties are targeted by the various methods: primarily texture, organic matter, compaction/bulk density, pH and nitrate (Table 4.4).

The only sensors widely used now are the electrical and electromagnetic ones, that also have the wider spectrum of activity over soil properties. At the same time, electrochemical sensors are a promising tool to directly evaluate soil chemical fertility (pH, nutrients).

Table 4.4. Soil properties targeted with various on-the-go soil sensing methods. Adapted from Computers and Electronics in Agriculture, 44, Adamchuk et al. On-the-go soil sensors for precision agriculture, 71-91, © 2004 Elsevier B.V., with permission from Elsevier.

Soil Properties	Electrical, electromagnetic	Optical, radiometric	Mechanical	Acoustic, pneumatic	Electro-chemical
Soil texture	X	X		X	
SOM[a]	X	X			
Soil moisture	X	X			
Soil salinity[b]	X				X
Soil compaction[c]			X	X	
Depth variability[d]	X		X	X	
Soil pH		X			X
Residual NO_3, TKN[e]	X	X			X
Other macro-nutrients[f]					X
CEC[g]	X	X			

[a] Soil Organic Matter (or soil organic carbon).
[b] Or sodium content.
[c] Or bulk density.
[d] Depth of topsoil or hard pan detection.
[e] Total Kjeldahl Nitrogen.
[f] Potassium content.
[g] Cation Exchange Capacity (and other buffer indicators).

The constraints that remain to be overcome are the response lag, still inhibiting a direct on-the-go adjustment of fertilizer or lime application, and the need to calibrate the analytical system like in a conventional laboratory, prior to operating. More to that, in a subsequent study (Adamchuk et al. 2005), the precision of eight electrodes, assessed in a comparative trial, remarkably decreased for the tested parameters in the order: pH, K, nitrate-N, Na, showing the need for additional work, in order to ensure a good reliability.

Among electrical and electromagnetic sensing, the measurement of apparent soil electrical conductivity is mentioned as the most reliable and frequently used to characterize the spatial variability in soil edaphic properties (Corwin and Plant 2005). Its greatest potential is deemed by the authors to provide reliable information for directing soil sampling to better identify and characterize spatial variability of parameters influencing crop yield.

6.2.2 Crop sensing

Hints of the direct measurements made on growing crops, in order to spatially-modulate inputs, have already been given in the nutrients and water sections, where ground and remote optical sensing of crop nutritional status and satellite sensing of ET fluxes were discussed. More to that, it may be said that, according to Scotford and Miller (2005), the optical techniques of spectral reflectance seem best suited for aiding decisions in crop nutrition until the crop attains full soil cover, yet reveal limitations as to weed and disease assessment, as well as to seed-rate adjustment on the base of seedbed quality. Likewise, spectral reflectance is unlikely to be used for measuring soil properties that are better evaluated by other means.

Crop sensing may be viewed as the most advanced sector within precision agriculture; at the same time, it seems more promising in combination with other tools, than alone. In fact, the association of a simulation model (CROPGRO) and aerial sensing (analysis of the Normalized Difference Vegetative Index) was successfully tried (Basso et al. 2001), enabling the identification of spatial patterns of soybean growth and the prediction of yield variability, thus fostering the idea that a zone-specific management can be developed, based on the association of the two techniques.

Auernhammer (2001), too, pointed out as the two strategies for implementing both fertilisation and protection, yield mapping integrated by soil sampling and crop sensing, may in fact converge into a systematic approach, where the potentials of the two means are enhanced, while the weak points are reciprocally compensated. In concept, this corresponds to passing from farming by balance (mapping approach) or by growth (real-time approach) to farming by sustainability (Fig. 4.9).

6.3 Other issues in precision agriculture

The site-specific management of crop nutrition remains the issue of major weight in the move towards precision agriculture, according to Auernhammer (2001). The resulting advantage is, therefore, quite small, and it is perceived that the technique will gain importance only when collateral benefits, such as reduced environmental burden and increased flow of information, are acknowledged as an added value. As to this, an environmental benefit of primary importance has been shown by Sehy et al. (2003), who observed how site-specific fertilizer treatments (method of previous-yield maps), supplying less N fertilizer to low-yielding areas, resulted in 34% less releases of the highly-noxious nitrous oxide from the soil, while not depressing maize yield.

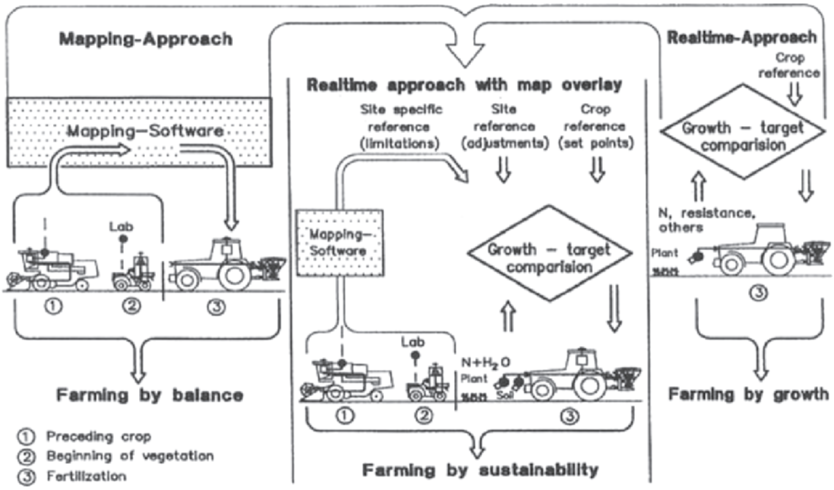

Fig. 4.9. Systematic approaches for the implementation of site-specific fertilisation. Reproduced from Computers and Electronics in Agriculture, 30, Auernhammer, Precision farming - the environmental challenge, 31-43, © 2001 Elsevier B.V., with permission from Elsevier.

The issue of an adequate return from the adoption of precision-agriculture techniques is only second in importance to the problem of which system to choose. To this aim, Godwin et al. (2003) have laid out a practical guideline in the shape of a flow chart, based on their experience on nitrogen fertilization of winter cereals in the UK. Five stages are identified: i) an appraisal of within-field variation; ii) the quantification of the threshold yield increases needed to justify the investment; iii) understanding the causes of variability and identifying management zones; iv) addressing fundamental management practices (e.g. other nutrients; non-nutrient limiting factors) prior to N variable application; v) the real-time management of variable nitrogen fertilizer for optimising economic yield. The five-step process allows to correctly evaluate all the factors implied in precision cropping, in order to implement it on a sound basis.

On conclusion, precision agriculture is a domain of rapid scientific-technical development, where today's knowledge, assumptions and results may soon be obsolete. Basically, it does not contribute new concepts to agronomy, whereas it promotes a re-organisation of agricultural practices, on the grounds of a better compliance with the characteristics and the potential of the cropping site.

7. Harvest, conditioning and storage

Harvest and subsequent conditioning/storage of crops for industrial end uses is another category that cannot fit simplification. The plant organs of industrial interest are the most varied: seeds, possibly with the associated fruits; stems; the whole above-ground biomass; or even roots or underground storage organs. According to this, a first subdivision may be traced between grain crops for industrial end uses and "biomass" ones, meaning for the latter those crops where the portion of commercial interest is represented by vegetative organs.

7.1 Grain crops

Harvest, conditioning and storage of common grain crops for industrial end-uses, such as many cereals and oilseeds, are widely known and represent a state-of-the-art that in the present chapter seems needless to discuss.

Maybe the only exception is represented by oilseed rape (*Brassica napus* L.), a cruciferous in which harvest time and method are basic determinants of crop yield. In fact, Weiss (1983) reported that yield losses may be up to 30% due to an incorrect use of harvest machinery. Oilseed rape is considered mature when pods become yellow and seeds very dark with a moisture of about 15%. This usually occurs about 200-230 days after sowing autumn crops and 100-130 days after spring ones, but the species is also characterized by a progressive bottom-to-top ripening, associated with the risk of pod-shattering. Given this constraint, the optimum harvest window may reduce to only one week (Weiss, 1983). The best technique, according to the species' biology, consists in cutting and windrowing the stems when pods at mid-height become yellow, then threshing with a pick-up combine when full maturity is achieved. It is essential that cutting occurs at a seed moisture not exceeding 35%; operating below 20% and over 45% will cause significant losses, respectively on yield (pod shattering) and quality (oil and protein content). The alternative is to combine the standing crop, at a more-advanced maturity. Combining either directly or from windrows is the single operation that causes the largest losses: the small size makes the rapeseeds easy to disappear at the cutting edge or through the smallest cracks and holes in the machines.

After combining, rapeseeds have a moderate-to-high moisture (approx. 15-25%), requiring a rapid air-drying (to 7-9%) to be carried out, in order to avoid seed deterioration: in fact, only 24 hours are needed to start seeds deterioration at 20°C and 18% moisture. Besides, a number of impurities are normally present with the seeds, therefore re-cleaning is often necessary to prevent contamination and heating in bulk.

7.2 Biomass crops

7.2.1. Herbaceous biomasses

In general, proper biomass crops are tall and stiff (e.g. giant reed, Miscanthus). As such, standard mowing machines for grass and forage crops do not generally work well with them and need to be adapted in order to successfully perform, though in some cases this may be untrue, as some biomass crops were found to be very suited to common forage machines without adaptations (Venturi et al. 2004; Hadders and Olsson 1997). For example, in Miscanthus the 'Kemper' mowing attachment used for silage maize should be row-independent and work rather high to prevent jamming. In this case, most biomass could be lost unless a special mowing device for low-cutting is added (Lewandowski et al. 2000).

Various harvesting chains have been tested so far: mowing and chopping, mowing and baling; mowing and bundling, etc.. If feasible, baling should be usually favoured, as it leads to a more compacted material at higher energy density. For example, the bulk density of round and square bales of switchgrass were from 112 to 141 kg m^{-3} of dry matter, while chopped material did not reach 70 kg m^{-3} (Venturi et al. 2004). Moreover, the choice of the harvest method also influences the costs per energy unit for the subsequent storage and transport. As for this, Venturi et al. (2004) calculated that 1904 and 2131 MJ m^{-3} are transported, using round or rectangular bales, respectively. Hence, with an available volume of approx. 30 m^3 (truck plus trailer), 57.1 and 63.9 GJ can be delivered each time. As for biomass sorghum, harvest is further complicated by the fact that problems associated with sweet sorghum are different from those of fibre sorghum, the first having much more soluble sugars in the stem.

In the Mediterranean area, the best available technique may be cutting and conditioning in one pass (counter-rotating drums), then windrowing to air-dry the material and finally baling it up by means of a high-pressure-chamber baler. However, meteorological constraints frequently delay the windrow drying, thus favouring fermentation processes while increasing biomass losses, especially in sweet sorghum. Sugar cane harvest machines can be very suited for sweet sorghum as well, although they generate cut stems of about 0.3 m length which can be stored no longer than 3 days prior to processing, making them of limited practical use.

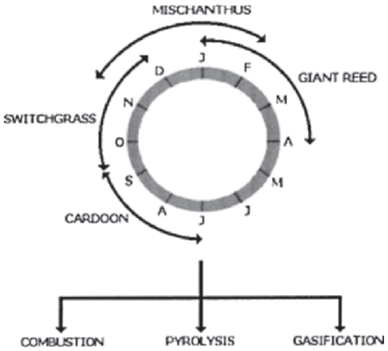

Fig. 4.10. The organisation of the supply to power plants, by means of biomass crops harvested around the year. M. Christou, internal meetings, EU Project Bio-energy chains from perennial crops in South Europe (2001-2005).

As for the relationship between harvest time and biomass quality, generally speaking, the later is the harvest, the lower are moisture and mineral content, thus enhancing the quality of the harvested biomass. However, there is a trade-off, since postponing the harvest to the springtime has a cost in terms of yield, mostly explained by leaf losses (Huisman and Kortleve 1994). For many biomass crops, the harvest window may extend from early autumn to the following spring, looking for the best compromise between full exploitation of the growing season's potential and acceptable operativeness at harvest. There are also exceptions of crops performing a rapid growth before the onset of drought, like cardoon (*Cynara cardunculus* L.), which in turn enable a better round-the-year supply of "fresh" biomass to power plants (Fig. 4.10).

For the rest of biomass crops, whenever the steadiness of supply can be achieved through storage, harvest is more often performed in spring, in order to collect a dry standing biomass, i.e. with the maximum uncut dry matter. Nonetheless, in spring the optimal time for harvesting can be very short because of the risk of heavy rainfall, associated to the need of sowing the following crop (annual biomass crops), or to the beginning of plant regrowth (perennial crops), that in temperate regions usually occurs in early April. Alternatively, many biomass crops may be harvested twice a year: early in the season (during summertime) at top moisture, followed by field-drying; then in winter, exploiting natural freeze-drying from the season's frosts. The outcome in terms of yield, quality and economic profitability is still under evaluation. Artificial drying or ensiling does not seem worthwhile for biomass crops at energy uses.

There are unavoidable losses of dry matter during harvest and storage of plant material (Moser 1980), either one or the other being prevalent depending on climate conditions, harvesting method, biomass composition, the last term being especially related to moisture content. For example, Rees (1982) estimated the total dry matter losses up to 30% with most of it resulting from plant respiration during drying; Coble and Egg (1987) showed total harvesting losses up to 40% for sweet sorghum, due to unrecoverable biomass.

Biomass losses may be also affected by the shape of the harvested biomass: it was shown that an almost two-fold deterioration of sweet sorghum occurred in the surface layer for outdoor storage over six months (Coble and Egg, 1987). These results were corroborated by Bledsoe and Bales (1992): the authors concluded that a wetter biomass was the main cause for the losses, the upper 0.15 m being more weathered than inner parts. Therefore, all the techniques which decrease rain seeping or allow a better drainage may strongly reduce storage losses (Russell and Buxton 1985).

At last, some crops such as switchgrass have been found to be less susceptible to biomass losses both during harvesting and storing. For example, Sanderson et al. (1997b) estimated biomass losses during baling of switchgrass at 1 to 5%, while dry matter losses after 12 months of storage were only 5 to 13%.

7.2.2. Short rotation coppice

An even more substantial research and development effort has been carried out in the mechanisation of the short rotation coppice (SRC) during the last decades. However, some issues still persist, mainly concerning harvest and the associated downstream processes that are clearly the most significant points in terms of overall effectiveness of the enterprise. Typically, the most suitable SRC within Europe are types of poplar (*Populus* spp.), willow (*Salix* spp.) and Eucalyptus, the last being especially adapted to Southern Europe. Harvesters can synthetically split into two categories: i) stick harvesters, i.e. machines collecting long sticks or shoots; ii) cut and chip harvesters, i.e. those cutting and chipping the crop in a single pass. Both may have advantages and disadvantages. For example, stick harvesting is generally cheaper and has lower biomass losses; in contrast, it needs large storage space: indeed the low bulk density of sticks make the transport expensive in conventional systems. At present, cut and chip harvesting seems favoured by the larger operations feeding chips to power-generation plants (Culshaw and Stokes 1995). This could be mainly attractive where the chips go straight from the field to a combined heat-and-power plant which can burn them within a few days from harvest.

Another problem associated with perennial biomass crops, both grass and tree ones, is that, since they are usually harvested in the winter months when soils are often wet, soil compaction becomes an important issue with respect to harvesting technique; in fact, since there is no opportunity to carry out cultivation operations to repair any soil-structure damage over the plantation's life. Soil compaction can be minimized by using large tyres, keeping machines weight as low as possible and by reducing unnecessary traffic across the field.

7.2.3. Fibre crops

Prominent fibre crops (cotton, flax) already own well-developed harvest-and-conditioning chains with dedicated machinery, fine-tuned logistics etc., the occasional difficulties arising from unfavourable weather, crop faults (e.g. biotic stresses, non-uniform maturity) or other causes.

In contrast to this, hemp was a traditional fibre until it almost disappeared at the advent of artificial fibres, in the second half of the twentieth century. The crop is now undergoing a process of re-introduction through a better valorisation of its fibres. In this frame, the development of a suited harvest-and-conditioning chain is to be thoroughly re-designed, according to the end use of hemp fibre: for example, it must be taken into account whether or not to use core and bark separately, whether or not to maintain fibre parallelism, the fibre length demanded by the end-user, etc.. However, not only the end use but also the processes following harvest are crucial for the choice of the machinery; for example, if scutching is done before or after retting, fresh or dry stems will be used.

For textile destinations, machines for flax could be used, apart from the fact that their hackling systems are dimensioned for fibre ribbons varying from 0.9 to 1.1 m, which are substantially smaller than that of hemp. However, the construction of hackling systems for the processing of longer stems, though already technically feasible, is likely too expensive because of the currently-limited hemp market. It is therefore necessary: i) to keep the hemp plants short ("baby-hemp"), or ii) to cut the stems into two or more pieces, no longer than 1.2 m. The first option can be achieved by following appropriate crop techniques such as using early varieties, with high plant density (Amaducci et al. 2002), or curbing the growth by means of chemical treatments (i.e. the "standing dead"). However, because of the chemicals used, the standing dead is in contrast with ecological trends; moreover, it has received a poor rating due to low fibre quality. Alternatively, scutching and hackling could be achieved by cutting hemp stems into smaller sections. For that purpose, the crop is grown in the traditional way, whereas major changes must be applied to the harvester (Amaducci 2005), according to prototypes developed in a recent EU Project (HempSys).

Once harvested, successive phases (swaths turning, baling, fibre separation, etc.) can be performed by flax-dedicated machines without substantial modifications.

To cut the plant, different mowers can be used (see Venturi 2004 for review). For sparse crops with thick stems, rotary drums mowers with conveyor belts tend to work best, bashing the stems before cutting them, and with lateral separators to avoid wrapping of the fibre around the cutting organs. An interesting variant could be the use of a mower-conditioner that crushes the stems, removing part of the core, thus facilitating field-drying. Interesting outcomes were also found by combining mower and on-field decorticator: the mower leaves stems in swaths, followed by a decorticator with a pick-up that collects the cut stems for immediate decortications (Venturi 1970).

8. Conclusions

Agronomy and management of industrial crops are an area of some technical/scientific delay with respect to food, cash and forage crops. The reasons are the novelty of many such crops, and the research focus that has so far targeted subjects of mixed agricultural-industrial interest, instead of proper cropping issues. Despite this, the management of industrial crops may not actually be considered backward with respect to "conventional" crops, thanks to the transitive property of many advancements in agronomy.

Areas of potential recovery of the former over the latter still exist, especially in those aspects where a specific work has been tailored to the requirements of large-scale crops, such as in fertilization and irrigation; but the weak points are counterbalanced by the remarkable potential expressed by many industrial crops under several viewpoints: energy efficiency, reduced environmental impact, carbon-sink potential, renewable raw products replacing non-renewable ones, just to mention some of them. Others more are envisaged in the future, in the light of today's research commitment.

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