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Inventory and mechanisms of cultural control practices for weed management, a review

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ABSTRACT

An inventory of cultural control practices is undertaken by considering each practice for its biological selectivity with respect to weeds. Descriptions of cultural practices in the literature are often brief. Some recent syntheses neglect knowledge from older publications. Disagreement concerning the delimitation of these practices is common. Clarification of the knowledge base concerning the cultural management of field flora is required for "sustainable agriculture". The selectivity most often mentioned for each practice is limited to a few examples of taxa in a geographically limited area and is rarely considered in the light of general mechanisms of action on biological cycles. The controversial distinction made by many authors between preventive and curative methods is unnecessary. Each practice listed is presented with its biological target. On the scale of a single cultural cycle, thirty practices are compared. Each target tends to have a specific biological descriptor. Most of the practice target pairs have the disadvantage of having an extreme state opposed to that of the target. Crop rotations are described as successions between non-competitive crops or practices that encourage certain weeds on the one hand and cleaning crops or practices on the other. The latter mainly target diaspores that have a lifespan inferior to the planned cleaning duration. The allelopathic after-effects show three mechanisms. In temperate climates, rotations may be complex with respect to the diversity of crop and weed phenologies. Combinations of cultural interventions must take into account the mechanisms involved, particularly because some results could cancel each other out.

Introduction

"Cultural control" means the adjustment or the simple organization of cultural practices in order to reduce the effects of enemies. For several reasons, effective cultural methods are usually required for sustainable agriculture (Singh et al. 2009; Jabran and Chauhan, 2018). In the context of integrated or sustainable crop weed management and, more globally, field flora management; it is important to identify the possible effects of many cultural practices (Upadhyaya and Blackshaw,

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2007). In soil conservation agriculture, Ramesh (2015) and Lee and Thierfelder (2017, in "southern Africa") highlight several cultural control methods amongst other weed control methods. In "clean agriculture", Abouziena and Haggag (2016) list cultural control methods, amongst others.

Ambiguity and limits of definitions of cultural control

From the 19th century onwards, weed science literature regularly considers cultural methods of weed control. In effect, Chicouène (2013) found that these methods are considered in 48 out of the 51 weed control textbooks compared: they are continuously mentioned from the 19th century up to 1977, although each time they only represent a few pages. From 1977 onwards, these methods are omitted from some documents, which emphasize chemical control, however, a small number of authors take an opposing view (Buhler, 1999; Upadhyaya and Blackshaw, 2007; Jabran and Chauhan, 2018) and give priority to non-chemical methods, particularly cultural methods. Amongst these 50 works (adding Hatcher and Froud-Williams, 2017 and Jabran and Chauhan, 2018 to the list of 48 in Chicouène, 2013), 43 include basic partial syntheses on the subject. Their chronological order and the cultural practices concerned are listed in Supplementary file. This supplementary file includes all the known practices that are used to directly or indirectly exploit cultural cycles and which are likely to affect weeds. The delimitation chosen here for cultural methods corresponds to a broad conception, combining the views of different authors, roughly speaking; it consists of regrouping cultural methods and some of the preventive methods in Upadhyaya et al. (2007), Pawar (2009), Walia (2010) or Subramanian et al. (2011). Comparisons with the other authors would be more difficult. Amongst others, the F.A.O. synthesis (1986) provides three categories "cultural control, cultural practices, cropping patterns", which are not distinguished from one another, due to the lack of sufficient definition. The case of crop rotations taken from the textbooks in Supplementary file is set out in Table 1, which shows that they are listed under either strategies or control methods. Most of the references classify these practices under the heading of strategies, but according to two opposing trends: these range from eradication, extermination, destruction or control (for the first nine lines) to prevention (case for the last two lines and the article by Anderson, 2007). Where cultural control is defined (i.e. in thirteen of the 25 works in table 1, in lines 7 to 16), their classification coincides five times with strategy headings and is related to "control".

Table 1. Classifications of crop rotations as strategies from 25 weed science textbooks amongst the 42 in the supplementary file.

Notions of strategies		Classification as cultural	Reference
1	"eradication"	-	Brenchley (1920) with only "cleaning crops" (rotation not explained)
2	"extermination"	-	Pammel (1911)
3	"destruction"	-	Shaw (1892, 1893)
4	"control, destroying"	-	Muenscher (1936)
5	"control"	-	Klingman & Ashton (1982), Ross & Lembi (1985)
6	"holding, "control"	-	Bolley (1908)
7	"control" and eradication"	"cultural"	Ahlgren & al. (1951)
8	"control"	"cultural"	Chaudhary & al. (2011), Subramanian & al. (2011)
9	"control"	"cropping methods"	Robbins & al. (1942)
10	"Integrated Weed Management"	"cultural methods"	Hatcher & Froud-Williams (2017 : 366)
11	-	"cultural"	Singh & al. (2006), Walia (2010)
12	-	"cultural practices"	Altieri & Liebman (1988)
13	(except for prevention)	"cultural management"	Upadhyaya & al. (2007)
14	-	"agronomic practices"	Saraswat & al. (2011) Jabran & Chauhan (2018)
15	-	+ or * or – depending on the chapters	Naylor & al. (2002)
16	-	*	Gwynne & Murray (1985)
17	-	-	Muzik (1970), Zimdahl (1993), Hatcher & Froud-Williams (2017 : 3-4)
18	"preventive, prevention"	-	Long & Percival (1910), Craft (1975), Fryer & Matsunaka (1977)
19	"preventive"	*	Pawar (2009)

Key for the "cultural" column: "-": cultural not formalized or not specified. "*": cultural formalized but not encompassing rotations.

The application of the notion of strategy to cultural practices, particularly to rotations, therefore varies according to the authors, the interpretation of contradictions should be considered by clearly explaining the possible concepts of the control strategies. Depending on the textbooks or articles, cultural methods are perceived using broader or narrower time and space scales: they range through the choice of seed batches, the management of a crop (for example advancing or delaying planting date), to rotations. However, the latter is not integrated into cultural methods by Gwynne and Murray (1982), Pawar (2009) or p.p. Naylor et al. (2002). These different delimitations of cultural practices are not necessarily justified, or the corresponding practices are not all classified as such. The practices that they encompass are variously considered to be preventive or curative strategies, or are set out without reference to strategy. For a proper understanding of the notion of prevention, the level of reasoning should always be indicated (Chicouène, 2000b). The main strategies applied at the field spatial scale are compared in table 2: the authors in supplementary file could be located in different cells of the two columns compared. For example, the expression

"[...] preventive and curative measures" in the title of the article by Colbach and Cordeau (2018) does not give any information as to its content. Additionally, these notions and their levels of reasoning are not necessarily specific to cultural methods. These nuances are at best meaningful in a spatiotemporal context explicit to each use. Therefore, in order to fully understand cultural methods, other complementary criteria of these notions should be considered. Due to this confusion of possible reasoning, it is best to try and consider the list of cultural practices without taking any notice of this classification into ill-defined strategies.

Table 2. Comparison of 4 levels of reasoning for preventive and curative strategies (extract from Chicouène 2000b, with additions).

Examples of levels of reasoning:	A. preventive:	B. curative:
1. Presence of the taxon in the field	avoid any introduction of troublesome new taxa	eradicate the taxa (when this is feasible and important)
2. Stock of diaspores	prevent a stock from increasing	reduce a stock
3. Make provision (or not) for the next crops (or years)	limit the populations for the next crops and/or years	prevent the harmful effect of the vegetation in the existing crop
4. Development of the vegetation in the existing crop	intervene as soon as possible (on seedlings, at germination or when growth restarts)	intervene (just before harvest) on mature plants or when sorting the harvest

The reality of cultural control approaches

Approaches to cultural methods, therefore, prove to be quite rare in the literature. The possibilities that they offer would merit a simple inventory and an overall assessment of the knowledge base. With this in mind, and with the requirement of classifying cultural practices and their literature (books and articles), several descriptors are available and relevant, particularly the types of spectra of the activity or the types of selectivity (Chicouène 2009), which provide important guidelines for developing control methods. This essential theme of biological cycles is logically considered with respect to scales of timely effectiveness required as a priority for a field. To achieve this, it is useful to distinguish two main groups of cultural practices: on the one hand, those that relate to cultural successions in general (discussed in Chicouène 2006 concerning the issues of stocks of diaspores in the soil and Chicouène 2007a concerning phenology), which encompass the first three lines (especially cell A.3) in table 2, on the other hand, the remainder, i.e. reasoning based on a single cultural cycle (discussed in Chicouène 2016), corresponding to the entire contents of the last line in table 2, perhaps also to cell B.3. The aim here is to regroup the cultural practices and their approaches encountered in the literature. The comparative approach is based precisely upon their biological targets of weeds and equally on their limits. Only crops subject to rotations are considered, whatever the climatic zone. The main inputs are, therefore by order of complexity of approach: a single cultural cycle, followed by cultural successions. A general discussion is then proposed.

Reasoning on a single cultural cycle

This approach is focused on the organization or the operating cycle of a single crop, or on one year for a meadow in a seasonal climate. It consists of exploiting the characteristics of a cultural cycle, while considering only the future harvest, with a given weediness of the field before applying cultural methods. Generally, the main aim is to reduce the potentially strong harmful effect of weeds present at the moment the decision is taken, whether these weeds are in a resting state or actively growing.

Two scales of understanding are distinguished:

- The field with its stock of weeds in or on the soil,

- Seed batch production management, particularly as concerns the mimicking weeds of a crop cycle.

The cultural practices listed

How the inventory is carried out

The practices in the supplementary file and in some articles are grouped in table 3 (with six practices), 4 (with thirteen practices) and 5 (with ten practices corresponding to five descriptors which each have two extreme statuses): they originate from Chicouène (2016) except that the examples of taxa, observed in temperate oceanic climates, have been removed and that certain practices have been added (denoted by numbers "bis"). A few cultural practices that use high temperatures are not included in the table: composting (Shaw, 1892: 5, etc. in supplementary file), controlled burning (Muenscher, 1936: 60, etc. in supplementary file), soil solarisation (Radosevich et al. 1997; Naylor et al., 2002; Gupta, 2007; Pawar, 2009; Walia, 2010; Chaudary et al. 2011) and fertilizer types.

Concerning crop management, the literature contains 2 different logics:

- The logic least frequently encountered consists of aiming for the chosen crop's phytotechnical optimum, for example, "planting at optimum date" (Smith et al., 1995: 411; Lee and Thierfelder, 2017; Jabran and Chauhan, 2018). The presupposition probable in this case is that the crop benefits from the best compromise conditions to resist a maximum of possible weeds.

Table 3. Cultural practices with simple actions, without disadvantages from the point of view of weed science (Chicouène 2016 modified).

Practices, cultural descriptor	**advantages, targets**	**possible disadvantages, hypotheses for possible limits**
1) thorough sorting of seed batches: (Muenscher 1936: 18, 54; Ahlgren & al. 1951: 16, 126, 159; Zimdahl 1993: 99, etc. in supplementary file; Chicouène 2016)	(Upadhyaya & al.: 3-4), - mimicking weeds, - new species (or new genes, particularly those for herbicide resistance) in the field* spread by seed batches	-
1bis) choice of a cultivar that facilitates sorting	cultivars of *Fagopyrum esculentum* with large seeds in order to exclude the seeds of *Datura stramonium* more easily (Chicouène 2010)	(may select another mimicking weed)
2) cleaning of tillage or harvest tools, (Brenchley 1920: 44, Muenscher 1936: 55, Robbins & al. 1942: 63, Fryer & Matsunaka 1977: 23, Zimdahl 1993: 74-6, Smith & al. 1995: 40, etc. in supplementary file, Chicouène 2016, Evers & Bastiaans 2016)	(Upadhyaya & al.: 4-6, Singh & al.: 644-6), reduce the introduction of new taxa or genes in a field (or reintroduction when they have been eradicated)*	
3) spatial arrangement of planting (Ahlgren & al. 1951: 7, Fryer & Matsunaka 1977: 11, Altieri & al. 1988: 206, 221-2, Smith & al. 1995: 416, Walia (2010: 91, Drew & al. 2009, Boyer & al., 2016, against *Lolium rigidum* in cereals, Chicouène 2016)	regular dispersal of the crop in order to optimize smothering of seedlings or late emergence of heliophilous species	
4) crop shorter than the weeds (at least some stages) (Chicouène 2016)	- opportunity for visual identification of tall weeds at low density for localized destruction -application of a height selective method (contact with an electric boom or a boom imbibed with herbicide, lopping machine) if high density-frequency	(fallen or dwarf individuals (due to vegetation density, deficiencies, biological regulation) are not necessarily taller than the crop)
5) elimination of chaff (Boyer & al., 2016, against *Lolium rigidum* in cereals, Tideman & al. 2016 for *Avena fatua*, Chicouène 2016, Lee and Thierfelder, 2017)	reduces input to the soil of some mimicking weeds or crop residues	(reduces food for seed-consuming regulators and reduces ground cover by crop residues)
5bis) mixted cropping (King 1966: 418-9, Altieri & al. 1988: 205, 309; Zimdahl 1993: 182-3, Smith & al. 1995, multiple cropping 289-291, Poggio 2005, Malezieux & al. 2009, Gaudio & al. 2019) or seeding fall crop mixted with ephemeral frost sensitive cover	better interference (e.g. by complementary soil covering or allelopathy)	(selection of taxa that tolerate the chosen companion crops)

* common targets for 2 practices.

- The logic developed here (for example in tables 3 to 5), which is the most frequent, is to move away from the chosen crop's phytotechnical optimum, or even to choose a crop or a method of management in order to best avoid some particularly noxious weeds that are present, taking into account the known biology of crop and weed. Therefore, "cultural controls [...] usually only require modifications to normal production practices " (Pawar, 2009). For example, sowing is earlier as opposed to later (Naylor et al. 2002). The aim here is to strongly reduce a harmful effect by choice or adjustment of cultural practices: the risk is that yield may sometimes be slightly degraded or the operating costs changed by technical issues (for example, crop fall due to dense sowing, dirt and humidity in the harvested crop in the event of an early harvest), additional operations (e.g. sorting) or reduced working speed (for example due to a very low cut). Certain cultural choices sometimes use other methods, not directly cultural (for example, selective mechanical intervention becomes possible due to wide spacing of the crop rows studied by Drew et al. (2009) for wheat otherwise considered as dirty crops, or a crop where a roller pass is possible just after its emergence in order to break fragile stems such as those of *Datura stramonium* or *Xanthium strumarium*).

Technical classification of the list of practices.

The descriptors used to characterize the relationships with weed cycle's concern different aspects or steps of the cultural cycle; these are shown in tables 3 to 5:

- choice of the crops in the field: the "traditional" type of crop with respect to selective mechanical control selection, i.e. hoed crop versus smothering or competitive crop, species and cultivars, speed of development of ground cover, the height of the adult crop,

- planting technique: cultural associations, purity of batches with respect to weeds, row spacing (a dirty or easily invaded crop usually planted in tightly spaced rows to make the most of the available space is planted in abnormally widely spaced rows to enable hoeing), sowing density, mulch, planting under ground cover,

- harvesting technique: cutting height, chaff eliminated or not,

- Phenology by crop calendars: planting and harvesting dates (earliness of maturation), duration of the crop,

- Soil physico-chemical properties: field soil conditioners, control of crop fertilization, management of irrigation or draining.

Furthermore, in temperate or seasonal climates certain phenology data are linked to the timing of emergence and development according to the seasons: this means that some extra variables are involved, such as the dates for planting, selective weed control and harvest.

Table 4. Cultural practices with simple actions, with disadvantages in weed science (Chicouène 2016 modified).

Practices, cultural descriptor	**advantages, targets**	**disadvantages, limits**
1) change the soil's physico-chemical properties to adapt it for a crop (Chicouène 2016), soil conditioners (Brenchley 1920, Robbins et al. 1942, pH *in* Altieri et al. 1988), Kone et al. 2014, fertilization (Fryer *et al*. 1977, Klingman & Ashton 1982, Altieri & al. 1988, Lee and Thierfelder, 2017), drainage and irrigation-flooding (Robbins et al. 1942, etc. in supplementary file)	- acidophilous and low fertility weeds by soil conditioners and fertilization (Brenchley: 68-69, Robbins: 51-2), - nitrogenous fertilization against leguminous weeds (Robbins: 127), - hygrophilous species by draining (Muenscher 1936; Altieri & al. 1988)	Singh & al.: 865, nitrogenous fertilization (Long: 42, Altieri & al. 1988: 219, Jabran & Chauhan 2018) and potassium fertilization (Altieri & al. 1988: 219), encourage important weeds of the desired crop
2) localized fertilization (Walia (2010 to limiter weed access to nutrients) (Liebman & al. 2001, Upadhyaya *& al*. 2007, Chicouène 2016)	e.g. for maize, low fertility weeds are excluded from the row	encourages emergence of nitrophilous weeds on the row
3) continuous ground cover during an entire intercrop (Singh & al. 2006, Chicouène 2016, Baraibar & al. 2017)	restriction of emergence or development of heliophilous seedlings	obstacle to mechanical control of vigorous perennials [e.g.: evergreens in general, summer weeds in summer intercrops, winter weeds in winter intercrops]
4) presowing cultivation (Walia 2010: 93, Chicouène 2016)	early and/or rapid emergence prior to the crop	slow emergence (e.g. deep origin, especially of vegetative organs) appearing earlier in the crop
5) mulch (Muenscher 1936, etc. in supplementary file, Chicouène 2016)	small seedlings	Muenscher 1936, for a sp. with vigorous new growth, Smith *& al*. 1995 for emergence of certain winter annuals, leaves large seedlings (vigorous, easily passing through the mulch, particularly those originating from large vegetative organs in the soil, difficult to hoe in the mulch)
6) high sowing density (Robbins & al. 1942, Ahlgren & al. 1951, Muzik 1970, Altieri & al. 1988, Zimdahl 1993, Smith & al. 1995: 447, Upadhyaya & al. *2007*: Walia 2010: 91, Chicouène 2016, Evers & Bastiaans 2016)	increases the interference of the crop with respect to sensitive, (heliophilous?) *sp*..	(selects weeds with increased competitiveness with respect to this crop, which may be etiolated)
7) direct sowing below smothering ground cover (e.g. frost sensitive cover for end of summer planting in temperate climates)(Upadhyaya & Blackshaw 2007, Chicouène 2016, Jabran & Chauhan 2018)	small heliophilous seedlings *	prevents mechanical control before seeding (e.g. to destroy vegetative organs)
8) sowing with early weed control in spring (e.g. maize in temperate climates) (Chicouène 2016)	limits early seedlings and their ground cover	encourages late emergence of thermophilous weeds (at the end of spring) in early spring crops
9) smothering crops, cover of the crops or the ground cover (Muenscher (1936, etc. in supplementary file, list of crops with variously competitive cover and mechanisms, in Smith & al, Jabran &	small heliophilous seedlings *	sometimes completely ineffective against sciophilous weed seedlings (including tall climbing weeds in tall crops) (*Galium aparine* in Drew & al. 2009)

Chauhan 2018) (Chicouène 2016)

10) traditional hoeing (included in mechanical control in the crop) (Brenchley 1920: 49, etc. in supplementary file, Chicouène 2016)	(mainly useful for short-lived diaspores in the context of rotations, Chicouène 2006, 2007a)	can leave the way open for stoloniferous weeds (particularly those rooted on the row at the time of hoeing) in damp soil and climate conditions
harvest advanced by several weeks: (Chicouène 2016)	anticipate the late development of very harmful individuals	-
11) harvest: winter barley versus late triticale (anticipate the choice of the crop (species, earliness of the cover) to achieve sufficient maturity)	anticipate the cover of the crop by summer weed growth	may encourage reproduction in stubble in the absence of stubble plowing or planting of a new crop
12) silage *versus* harvesting of cereals	(Cussans *& al*. 1976: 128), prevents the formation of a stock of diaspores of: - many weeds with summer maturity (especially tall ones during cutting) - including mimicking weeds	may encourage reproduction in stubble in the absence of stubble plowing or planting of a new crop, particularly of stoloniferous weeds that pass under the reaping machine
13) potatoes (anticipate the choice of harvest earliness crop with a short cycle, harvest before the maturity of the skin = as "new potatoes", not main crop)	- anticipate damage caused by couch grass rhizomes (various species) on tubers, - anticipate aerial invasion during the harvest (e.g. herbaceous lianas that risks jamming the rotating shafts of harvesters)	frees up the soil early, which risks allowing weeds not affected by the crop to continue their cycle

* common targets for 2 practices in the table.

The biological targets.

The types of targets for each practice are assessed with reference to a cultural optimum without weeds: they are shown in the second column of tables 3 to 5.

General characteristics of the targets.

Several criteria are used to characterize the targets. In the literature, the most easily encountered criterion is their taxonomic spectrum. The latter corresponds to a few taxa with very specific biological characteristics such as a restricted period of emergence, at least for production of vigorous individuals, to the entire heliophilous flora, i.e. except for sciophilous weeds or even climbing weeds. The biological selectivity proposed in tables 3 to 5 has a general overall value. Its descriptors are quantitative when a time difference to the phytotechnical optimum can be expressed as a number of days or as dimensional units (especially absolute or relative heights). The level of effectiveness expressed as a proportion of repression could possibly be proportional to the intensity of the practice carried out or to the divergence from the phytotechnical optimum. The experimental data on these aspects and their relationships remain limited (for example between sowing density and crop yield in a field more or less densely infested with heliophilous and non-climbing weeds). Most of the practices retained, i.e. 25 out of 30, have a specific biological target. In most cases, the latter is already mentioned in the bibliography. These targets are independent of one another except when mimicking weeds are particularly concerned: they may then be redundant and/or complementary (subject described later). The targets are described by phenology, ecology (especially of emergence and seedlings) and morphology. Most are considered primarily within a single cultural cycle. Some that concern the soil will act during several successive years.

Table 5. Cultural practices with extreme state-effect pairs (reversed from the point of view of weed science).

Cultural descriptor, practices	Advantages, targets	Disadvantages, limits
1) date of sowing in seasonal climates: (Ahlgren & al. 1951, etc. in supplementary file, Chicouène 2016, etc.)		
1a) anticipated sowing (especially of a different crop or a crop disadvantaged at the end of its cycle)	the ground cover discourages *sp.* with late emergence (heliophilous weeds...) discouraged by the ground cover or by the time-lapse with respect to soil disturbance, e.g. in a fall crop with *Avena fatua* (Cussans & al. 1976), with *Veronica hederifolia* (Lee and Thierfelder, 2017)	encourages *sp.* with early emergence (simultaneous with that of the crop) or species with significant vegetative development at the same time as the start of crop development, e.g. in a spring crop with *Avena fatua* (Cussans & al. 1976)
1b) delayed sowing (different crop or a crop disadvantaged by a shorter cycle or exposed to stressful conditions)	avoid sp. with only early emergence, or those remaining stunted if emergence is late, e.g. in a spring crop: *Avena fatua* (Cussans & al. 1976)	- encourages heliophilous *sp.* with late emergence, e.g. - in fall crops (winter emergence) - in crops at the start of spring, thermophilous weeds (emergence at the end of spring)
2) crop height: (Smith & al. 1995, tall cultivars of small grain, tall crops: 81, 83, 286; etc. in supplementary file, Drew & al. 2009, Chicouène 2016)		
2a) tall crop (e.g. rye, oilseed rape, buckwheat, hemp)	more or less smothers dwarf heliophilous weeds	encourages tall climbing weeds
2b) low crop (spring barley, beet)	- discourages tall climbing weeds - and see table 3,4	encourages dwarf heliophilous weeds
3) harvest date: (Cussans & al. 1976, etc. in supplementary file: Chicouène 2016, Tidemann & al. 2017)		
3a) harvest or mowing anticipated by a few days	reduces input to the soil of caducous diaspores at complete maturity of the crop	humidity and contamination of the harvested batch by *Avena fatua* at the milky stage
3b) - harvest delayed by a few days at the harvester	the batch harvested is purer and drier because the targeted diaspores have mostly fallen onto the soil	input to the soil stock from the weeds targeted in the preceding column
4) cutting height: (Hakansson, 2003; Chicouène, 2016)		
4a) high cut (less straw to pass into the combine harvester)	limits the entry of dwarf plants into the combine harvester (limits blocking of the blades)	input to the soil stock from the weeds too low to be cut, (Hakansson, 2003)
4b) low cut with crop lifters (lots of straw filling up the combine harvester)	can avoid the input of just-ripe diaspores to the soil, especially: - fallen mimicking weed individuals - dwarf plants	increases contamination of the harvested batch
5) row spacing (Jabran & Chauhan 2018: 102-103...)		
5a) reduced (for rice, soybean, wheat)	crop distribution increasing its smothering power (Chaudary & al. 2011: 96, Walia, 2010, Borger & al. 2016)	prevents any hoeing
5b) increased for durtying crops	allows hoeing or localized treatment	- reduces the smothering power of young crops, - increase emergence of heliophilous weeds between the rows

Relationships between targets and harmfulness.

All types of harmfulness as listed by Chicouène (2010, in major temperate crops) may be anticipated. They are not restricted to yield, sometimes the only type considered in publications. They concern the other aspects, which are, on the one hand, technical problems (e.g. in order to avoid late vegetative invasion interfering with the harvesting operation, an early harvest is considered), on the other hand, toxicity, particularly sorting of food harvests. In the latter situation, due to the low thresholds of harmfulness, high levels of effectiveness are sought. For example, a buckwheat cultivar with large seeds renders the elimination of *Datura stramonium* seeds easier in harvests from infested fields. Careful sorting of batches earmarked for consumption or sowing for some *Lolium* such as *Lolium temulentum,* a mimicking weed in wheat, is a subject described later.

The reverse effects of biological targets.

Types of biological spectra concerned

Weeds are compared with one another here by considering their biological diversity. The non-target part of ~~a~~ practice has two levels. From a general point of view, "cultural controls may be effective for one pest but may be ineffective against a closely related species" (Pawar, 2009: 161). We must also distinguish the case where the practices encourage enemies: the phenomenon is encountered for most of the practices considered by Chicouène (2016). In the bibliography, this subject is considered far less often than the targets because it requires the characterization of several taxa with respect to each other. Specifically, in the last column of tables 3 to 5, the limits (table 3) and the disadvantages or reverse effects (tables 4 and 5, i.e. respectively thirteen and ten cases) corresponding to each practice-target pair are explained. Thus, case 5.1 of the planting date chosen to be unfavorable for a specific type of emergence calendar is at the same time the most optimal for taxa responding in a contrary manner to this date. The dilemma becomes crucial in a field when at least one weed requires one measure and at the same time, another weed justifies the opposing measure or risks selecting this latter taxon. The characteristics of a non-target flora opposed to the target of the practice considered should be rationalized at the scale of an area geographically greater than that dominating the single field at a given moment: species known to be major weeds in nearby fields may be selected so long as they are present.

Interpretation of reverse effects.

The most quantitative targets see their reverse effects described by the same descriptor but in the opposite direction: proportionality can be considered between the two directions of description. In table 5 itself, the targets and their reverse effects tend to be inversed in pairs by descriptors with two opposite extreme states. This aspect already noted by Chicouène (2016) gathers together more cases here.

Table 2 (ligne 1) describes the soil physico-chemical properties. Modifications of these may have an effect on several successive cycles or on several cultural successions in the field. Liming in acid soils encourages some taxa at the expense of others (e.g. Koné et al., 2014, on rice in Benin). The ecological interpretation would be that the most neutrophilic weeds replace the most acidophilous weeds by several hypotheses of mechanisms (competition or interference, or the neutrophils weeds colonize after the acidophilous weeds are eliminated due to the toxicity of calcium for the latter, or to higher levels of parasitism, or sometimes by a choice of crops that are more competitive in these conditions). Over a cultural cycle, numerous mechanisms, therefore, seem to come into play and the interpretation hypotheses are proposed with varying precision in the last column of the three comparison tables. In the same way, as for targets, the avenues of plant architecture and of physiology are equally important but via their opposite status. The choices between the different cultural practices depend on the dirtying of the field or the crop, by considering the various types of parameters present and their integration into the production cycles. Consideration should also be taken of the possible consequences of these decisions over the following years.

Case of mimicking weed taxa in seed batches.

Linked to the subject of cultural successions, there are numerous cultural practices concerned in tables 3 to 5 that justify placing mimicking weeds in the part concerning a single cultural cycle.

Issue of the harmfulness of mimicking weeds.

Concern for the purity or sorting of agricultural seeds appears regularly in the books in the supplementary file, especially the oldest ones (in the 11 published before 1970, then in 21 out of the 31 published later). The principle consists mainly of taking account of taxa new to a field or taxa reintroduced after their eradication (Chicouène, 2000b). This subject particularly concerns mimicking weeds of crop sowing and harvesting cycles. They are taxa "closely associated with a particular crop" (Barett, 1983). Some taxa are close relations of the crops, of which they may be ancestors: Altieri & Liebman (1988: 61 & 221) mention several species in this case. The subject is also important when the diaspores concerned are toxic as are some species of *Lolium* in several small-grain cereals and in linseed. The case of control of *Lychnis githago* is discussed by Brenchley (1920), who recommends sorting just before the harvest. However, the stages of the cycle where cultural control is feasible are numerous. These sorts of the plant are specifically targeted six times in tables 3 to 5 (lines 3.1, 3.1bis, 3.2, 3.5, 4.12, 5.4b). Comparison of these interventions between each other shows effects that are either complementary (e.g. harvest and sorting in 3.1 and 5.4b), or redundant (e.g. cleaning tools in 3.2 and prevention of maturation in 4.12).

The cycle of crop mimicking weeds and control practices.

In the typical state, stocks of diaspores of mimicking weeds are logically limited to contaminated agricultural seed batches ("seed mimicry" in McElroy, 2014), passing every year from one field to another according to crop rotations that include the incriminated crop: in other words, their effective stock of diaspores in the field (on or in the soil) is, therefore, zero or close to zero. The contamination of an initially exempt cultivar batch can theoretically occur via several possibilities that determine the effective interventions (Figure 1).

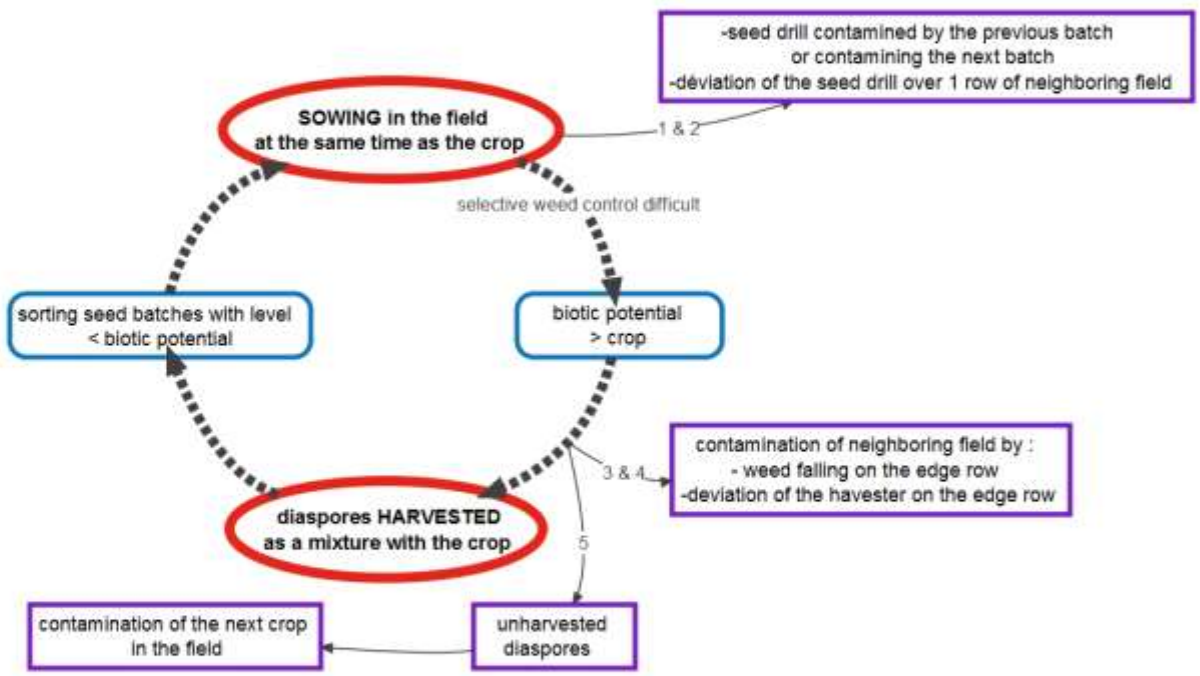

Figure 1. The cycle of a crop compared to that of a mimicking weed.

- by machines already contaminated by a preceding dirty batch (seed drill or harvester): vigilance concerning the cleaning of machines is mentioned several times in the literature in the supplementary file such as Brenchley (1920),

- or the edges of adjacent contaminated fields when tools pass over a row of the other field or weeds that fall in the first row of the neighboring field: these transfers of mimicking weeds between neighboring fields can be countered by various appropriate landscape works discussed by Chicouène (2004b),

- or via a very low but non-zero stock in the soil: when the harvester cutting height is not low enough, a few ephemeral diaspores that do not enter the harvester may remain on the soil (see table 5, line 4b).

Assuming abiotic potential greater than that of the mimicked crop, depending on the level of investment in these practices of cultural control, the infestation rate of the batch that has just been contaminated will either show slower progress compared to complete absence of control, or will be stabilized, reduced or eliminated. The subject of mimicking weeds is linked to cultural successions: the reasoning is an anticipation of the seed batch for the following year rather than the spatial scale of the same field in which a crop rotation takes place. The classification as a strict mimicking weed is valid in the context of a cropping system. Depending on the proportion of the stock, on the one hand in the seed batches, on the other hand in the soil (low or ephemeral), a quantitative classification of mixed taxa (i.e. partly mimicking weeds) can be considered.

For mimicking weeds, the biological targets do not have the issue of opposite targets.

Cultural successions

The principle is to exploit crop successions or even different ways of managing a crop, including intercrops, with the aim of limiting the infestations of the following crops. In the wider sense, this notion may encompass any practice that impacts weed cycles, whatever the control methods: in this context, these practices and their organization are intended to limit the effective stock of certain diaspores likely to emerge in a future crop.

General remarks concerning the historical descriptors of practices

The word crop "rotations" is quoted in 37 out of 42 books in the supplementary file. The more general expression of successions is rare (i.e. Hakansson, 2003). In that of Saraswat et al. (2003) or in the article by Andrade et al. (2017), the notion is labeled as "crop sequence". Although the subject is frequent, in nearly all the works the corresponding text consists of one page or less. Singh et al. (2006) is an exception, especially while dealing with two specific cases of geographical areas ("semiarid" and "Canadian Prairies", respectively with 21 and 31 pages) and that of herbicide resistance (in less than a page). The implicit criteria of alternation mentioned in the list of books quoted above are summarized and classified hierarchically in table 6 into six superior groups and 17 inferior groups. The precision of the definition of these groups is variable:

- The weakest conceptual formulation of descriptors is the simple mention of different cultivated taxa. This is the first group, with 16 references on species, one on families, one between Monocotyledonae and Dicotyledonae.

Table 6. Classification of the main descriptors of crop rotations in 36 weed control textbooks.

no.	Implicit group of descriptors	Descriptor of crops in rotation	Quoting of practices and reference
1.	crops only	cultivated taxa	- species of crops: Bolley 1908, Long & Percival 1910, Pammel 1911, Craft 1975, Klingman & al. 1982, Zimdahl 1993, Aldrich & Kremer 1997, Buhler & al. 1997, Radosevich & al. 1997, Monaco & al. 2002, Naylor & al. 2002, Hakansson 2003, Saraswat & al. 2003, Singh & al. 2006, Gupta 2007, Walia 2010, Subramanian & al. 2011 - family: Hatcher & Froud-Williams 2017 (p. 366), Jabran & Chauhan 2018 - grass vs. broadleaf crops: Smith & al. 1995
2.1	valuable cultural attribute	cleaning aspect explained	- drop certain crops out of the rotation: Shaw 1892 - clean cultivated: Muenscher 1936, cleaning crop: Naylor & al. 2002 - break crops: Gupta 2007 - root crop = clean farm: Long & Percival 1910, root cleaning crops: Brenchley 1920
2.2		mixed	- clean cultivated and competitive crops: Robbins & al. 1942
2.3		competition	- competitive crop: Robbins & al. 1942, Ahlgren & al. 1951, Craft 1975, Klingman & al. 1982, Naylor & al. 2002, Singh & al. 2006 - competitive vs. non-competitive crops: Altieri & Liebman 1988 - competitive ability: Pawar 2009, Hatcher & Froud-Williams 2017; variation in competing: Monaco & al. 2002
2.4		mixed	- smother or competing crops: Ahlgren & al. 1951
2.5		density of the ground cover	- smother crops: Robbins & al. 1942, Saraswat & al. 2003 - cover crops: Liebman & al. 2001, Naylor & al. 2002 - canopy development: Naylor & al. 2002 - closed and open canopies: Jabran & Chauhan 2018
2b	mixed		- fooling crops vs. cleaning with mechanical means: Altieri & Liebman 1988
3.1	use of other control methods	mechanical assumed: hoeing/not hoeing	- row crops: Ahlgren & al. 1951, Singh & al. 2006 - drilled and row crops: Ahlgren & al. 1951 - row crops and small grain: Ahlgren & al. 1951 - row crops vs. broadcast crops: Muzik 1970 - type of implement, tillage operations: Craft 1975 - cultivated crops vs. non cultivated: Anderson 1983 - cultural practices: Smith & al. 1995, cultivation practice: Jabran & Chauhan 2018) - fallow intercropping: Naylor & al. 2002; introduction of fallow : Singh & al. 2006, Pawar 2009, Hatcher & Froud-Williams 2017 (p.4, p. 167) - wide row crop: Gupta 2007
3.1b		mixed	- mechanical vs. chemical: Smith & al. 1995
3.2		chemical	- with or without herbicides: Liebman & al. 2001 - herbicides: Craft 1975, Klingman & al. 1982, Ross & Lembi 1985, F.A.O. 1986, Zimdahl 1993, Smith & al. 1995, Buhler & al. 1997, Monaco & al. 2002, Naylor & al. 2002, Singh & al. 2006, Walia 2010, Jabran & Chauhan 2018 - grass killers: Altieri & Liebman 1988
4.1	time	duration of the crop: perennial vs. annual	- small grain, pasture: Pammel 1911 - grain, clover, grassland for hay and pasture: Muenscher 1936 - grain, competitive crop, hayfield or pasture: Ahlgren & al. 1951 - perennial phases: Altieri & Liebman 1988 - perennial forage crops: Liebman & al. 2001 - pastures: Monaco & al. 2002 - frequency grazed or cut forage crop: Gupta 2007 - annual vs. perennial: Jabran & Chauhan 2018
4.2		number of days of vegetation	- transplanted rice: Saraswat & al. 2003 - rye cover crop in vegetable cropping: Singh & al. 2006

4.3		calendars and general phenology	- variation in timing of management practices: Liebman & al. 2001 - different growing period: Pawar 2009 - planting and harvest dates: Upadhyaya & al. 2007 - time of cultivation: Klingman & al. 1982 - time planted: Altieri & Liebman 1988, planting dates: Monaco & al. 2002 - timing of sowing: Naylor & al. 2002; season sowing: Hatcher & Froud-Williams 2017 - different harvesting dates: Altieri & Liebman 1988, Naylor & al. 2002
4.5		seasons (especially in temperate climates)	- winter vs. spring crops: Long & Percival 1910, Zimdahl 1993, Singh & al. 2006 - spring vs. fall-planted crops: Muzik 1970 - winter crop: Fryer & Matsunaka (1977 - winter cereal vs. spring: Gwynne & Murray 1985 - spring vs. fall-seeded: F.A.O. 1986, fall vs. spring crops: Jabran & Chauhan 2018 - winter vs. summer crops: Altieri & Liebman 1988 - winter vs. spring sowing: Naylor & al. 2002 -<u>number</u> of summer vs. winter crops: Singh & al. 2006
5.1.		richness (except leguminous plants)	- variation in fertility: Monaco & al. 2002 - exhausting crops vs. less demanding: Jabran & Chauhan 2018
5.2	<u>soil</u>	leguminous plants	- rotation soybeans: Robbins & al. 1942 - alfalfa occasional: Craft 1975, Altieri & Liebman 1988 - leguminous plants: Smith & al. 1995 - leguminous vs. non: Jabran & Chauhan 2018
5.3		other aspects	- soil conditions: Liebman & al. 2001 - tap rooting vs. fibrous: Jabran & Chauhan 2018
6.1		mixed methods	- summer row crop, winter grain crop: Klingman & al. 1982 - control techniques + rotation practices: Zimdahl 1993 - crop management practices: Liebman & al. 2001
6.2	<u>other cases</u>	outside classification	- kind of crops: Chaudary & al. 2011 - leaf crops, root and tuber crops, bulb crops, fruit crops: Hatcher & Froud-Williams 2017 - different life cycles: Upadhyaya & al. 2007, Hatcher & Froud-Williams 2017 - mixed cropping: Subramanian & al. 2011

- The cultural aspect includes several traditional descriptors of practices. Functions that are a priori cleaning in the succession are described in lines 2.1, 2.2 and 2.b, without mention of either taxonomic or biological targets. To compare the effects of rotations on weeds, Singh et al. (2006) consider additions to the density of all species combined. The notion of "break crops" (Gupta, 2007) implies targets of weeds mainly known as plant parasites (e.g. *Orobanche* in Labrada et al. 1994). A quality or capacity for competition or groundcover is mentioned in lines 2.3 to 2.5.

- Line 2.b serves as the transition with the use of other methods, specifically mechanical practices (line 3.1 with 11 quotes). Chemical practices are also quoted in the works from recent decades (line 3.2 with 14 references) either for their alternation with other methods or between different chemical practices.

- Temporal criteria include general ideas (lines 4.1 to 4.3) that encompass cycle length in the form of annual as opposed to perennial crops, or calendars or general phenology of the crop (number of days for some annual crops). In addition, in temperate climates, there are alternations of dates or seasons for planting and/or harvesting, with 11 references in line 4.5.

- The edaphic criteria (lines 5.1 to 5.3) during a rotation mainly concern strong fertilization for a crop that demands a soil rich in nutrients, followed by less and less demanding crops.

- Lines 6.1 and 6.2 correspond to rarely quoted criteria, which are more or less precise.

Biological mechanisms involved

The aspects of diaspore demography linked to the rotation are first presented in a general manner, and then focused on cleaning.

Shared principles for the organization of a cultural succession.

Concerns about the biological mechanisms involved when using rotations have developed progressively since the start of the 20th century. The notion of "cleaning crop" as mentioned by Brenchley (1920) remains a vague assessment. In weed control or agronomy textbooks, description of the succession is generally limited to examples of crops or types of crops, without strict recommendations concerning the choice of sequence. Alternation should logically be between dirty crops and cleaning crops, or even leaving the land fallow (i.e. Singh et al. 2006). The latter categories are presumed to precede the crop with the highest added value for the farmer, which would also be more sensitive to a given level of dirtiness. This concept of more or less regular empirical successions leads us to consider the underlying biological mechanisms. Several biological phenomena are already possible in the effects of a preceding crop. The case of the results of a rye crop as the main crop or as ground cover, especially when considered as mulch, is widely documented (see Singh et al. 2006). The effect of harvest residues on the development of weeds in the following crop is on the one hand mechanical by ground cover, on the other hand, chemical by allelopathy. It concerns the stock that may be active in the crop concerned. In addition, a direct demographic role depends on the non-renewed stock of diaspores. The essential biological descriptors relating to cultural successions are compared by Chicouène (2006). They are reviewed schematically in Figure 2.

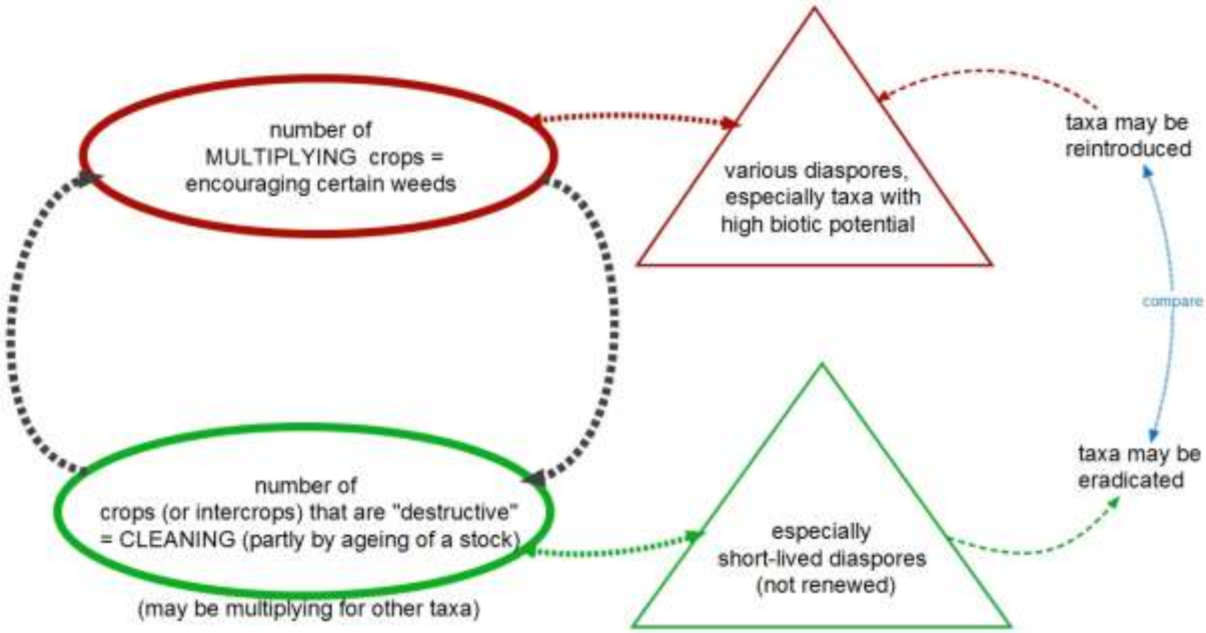

Figure 2. Main parameters of a cultural succession focused on diaspore stocks (Chicouène 2006 modified).

In a balanced rotation, in terms of taxonomic selectivity, the taxa that multiply in certain crops should theoretically be the same as those that are reduced by other crops; otherwise, after several cycles of the rotation, there would be important changes in the flora. However, in an ordinary succession such as that shown in figure 2, the question arises as to whether the multiplied and cleaned stocks should be considered as identical.

Organization of cleaning the stock of diaspores

Generally, cleaning implies reproduction inferior to losses during the cultural cycle, the ideal being the absence of reproduction. The time limit for the exhaustion of a stock of diaspores implies that the stock is not renewed during a time span that exceeds its life span. Prevention of multiplication (2nd line in table 2) at least avoids any increase of the stock. This strategy (Chicouène, 2000b) is of interest in two types of situation:

- For long-lived diaspores where the population is still very low in the field,

- For diaspores with lifespans shorter than the series of cleaning crops and intercrops, whatever the population level.

The usual mechanisms for the exhaustion of stocks are assumed to be of three types:

- Biological regulation (diseases and predation, the latter being considered particularly in the absence of soil cultivation by several publications),

- Death of dormant diaspores or diaspores that have germinated but failed to emerge,

- Emergence, which, depending on the taxa, is either encouraged or inhibited by recent cultivation of the soil (Chancellor, 1964; Chicouène, 1996).

These 3 mechanisms active during the cultural cycle and in intercrops.

As cleaning durations depend on the persistence of the diaspores, various strategies acting on the stocks are possible. They are summarized by Buhler et al. (1999). In the context of a succession, the survival curve of the diaspores determines the number of years required for cleaning. The absence of multiplication, therefore, concerns different scales of the time period:

- When the stock survives for less than a year or one cultural cycle, a biennial rotation is enough. Chicouène (2007a) lists the possibilities for destroying or preventing the renewal of vegetative short-lived diaspores when they are seasonal.

- Two years without reproduction is long enough to get rid of diaspores that survive for one year, several species of this type are studied by Froud-Williams and al. (1984).

- Three years are necessary for diaspores that survive exceptionally for two years (this is sometimes the case for *Arrhenatherum bulbosum* corms according to Le Clerch, 1976).

- If diaspore persistence lasts for many years, it is inconceivable to have a sufficiently long cleaning duration in the context of simple cultural succession.

Cleaning by putting the land into the meadow, managed either by mowing or grazing, is mentioned several times. Brenchley (1920) indicates some species that grow in both perennial meadows and annual crops. For weeds specific to annual crops, the survival of diaspores with life spans exceeding the time the land is kept under meadow is also mentioned by Brenchley (1920) and some limited comparative data are quoted by Altieri and Liebman (1988). So for *Avena fatua*, the caryopses survive in a three-year meadow but their stock is exhausted by three years of spring barley without reproduction.

Persistence of cleaning

The objective is to be able to plant the maximum number of crops that are potentially multiplying for major weeds, without this multiplication taking place due to the diaspores having been eradicated during a preceding succession: cleaning for these diaspores, therefore, becomes unnecessary. This strategy is put into perspective by Gupta (2007) who considers it to be an "expensive adventure" for an "area". In fact, it depends on the efforts that must be implemented for the complete cleaning of a challenging weed species in a field. This persistence of a valuable cleaning effect after eradication of an effective stock in the field obviously only lasts so long as recontamination does not occur. Reintroduction occurs in the same way as for any new species, by natural means from neighboring fields or by anthropochory (contamination of seed batches or tools). The precautions required to avoid this represent efforts that vary on a case-by-case basis (Chicouène, 2004b). When a species is reintroduced, the speed of recolonization of a field, i.e. the number of possible years for multiplying crops, depends on the density of the fresh contamination, the biotic potential of the taxon and the repression level of the control practices brought back into use for cleaning.

Special cases

The allelopathic after-effects of a plant

Whether they are weeds or crops, residues of individuals of certain species undergoing decomposition in or on the soil are known to have allelopathic properties (Singh et al. 2005; Albuquerque and al. 2011). These properties act both on weeds and crops. The study by Izzet Kadioglu and Yusuf Yanar (2004) on 22 species shows differences in selectivity. The compounds concerned may have been released into the soil while the organs were alive, or they may be produced during decomposition of the individual or of organs (Soufan and Al Mouemar, 2009; Albuquerque et al. 2011). These effects may originate from plants that grew in the same field, but could also originate from spread litter in the second case (e.g. rye straw mulch) possibly coming from another field. When the mode of action is the inhibition of germination, the risk is that these diaspores emerge when the allelopathic effect ceases. If this emergence happens in the crops where they are the easiest to destroy during the rotation (e.g. in a hoed crop, assuming that the preceding wheat crop was protected by the after-effect of a buckwheat crop) then the rotation is justified. These notions are listed in figure 3. Logically, the cleaning of the stock of diaspores only exists for those whose lifespan is inferior to that of the inhibition of germination. Knowing how long the two types of effect last and what the spectrum of activity is for each very allelopathic plant would be valuable for improving the design of rotations. Research into their kinetics should also be considered in the context of experimental cultural successions.

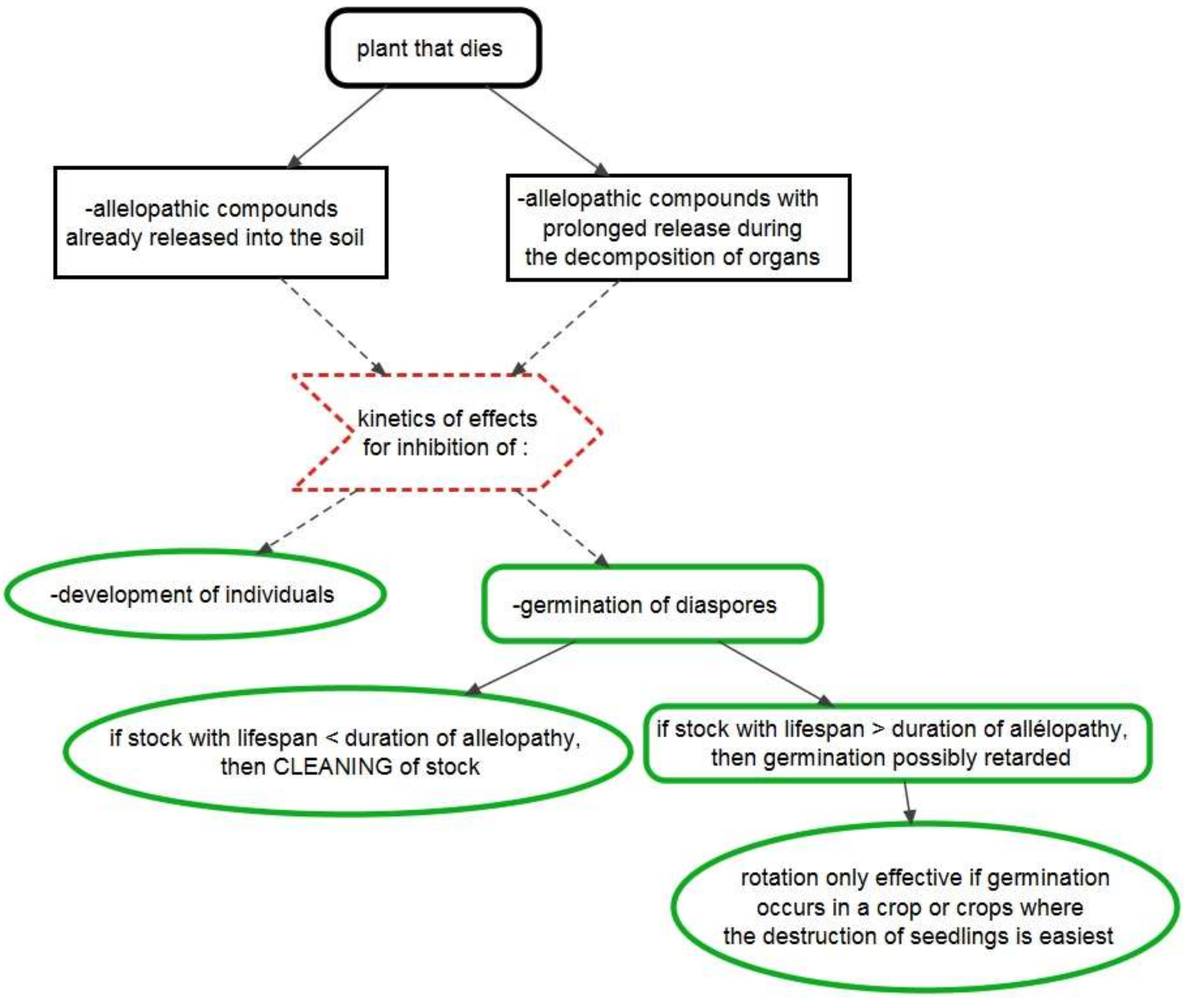

Figure 3 . The three mechanisms of allelopathic after effects in a cultural rotation.

Introduction of occasional plowing and soil disinfection.

Occasional plowing and soil disinfection are considered in cultural succession sensu lato by Chicouène (2000a); these interventions between two crops are not shown in figure 2. They lead to instantaneous cleaning only in the case of emergence with an origin close to the surface. These two methods have slightly different characteristics:

- Occasional plowing, with jointers to facilitate turning of the cultivated soil, acts on diaspores causing superficial emergence that have life spans inferior to the interval between successive plowing operations or to the time interval between their production and the plowing. However, many studies show that burying tends to increase the persistence of seeds to a greater or lesser degree depending on the species (Buhler et al. 1999).

- Soil disinfection (by thermal methods such as steam or solarisation or by chemical methods) destroys the diaspores causing superficial emergence irrespective of their usual survival span.

These two techniques prevent emergence from stock located at depths greater than the emergence depth limits of a proportion of the taxa. Effectiveness only lasts so long as there is no reintroduction or reinfestation of the superficial zone. Tools that cultivate the soil to depths greater than the disinfected depth or the depth of origin of emergence (some tined cultivators) could a priori neutralize or reduce the performance of the two operations mentioned.

Taking chemical control into account.

From the point of view of weed science, a crop type is characterized by its cultural practices. With the expansion of chemical control, Chicouène (2013) notes that several authors of recent textbooks only separate crops from one another by the herbicide programs adapted to each crop. This attitude is at the limit of cultural control described in table 6 (lines 3.1b and 3.2). Within a rotation, the impact of the herbicides is integrated into the impact of the crops in the articles by Anderson (2007), Andrade et al. (2017), Colbach et al. (2017) or considered separately by Singh et al. (2006). McElroy (2014) even proposes to extend the notion of mimicking weed to selection by chemical control. In light of the fact that the available chemical arsenal varies over the years, observations on the impacts on the crops tested should be interpreted according to the spectra of activity of each herbicide used during the trials.

Temperate climates.

In temperate type seasonal climates, planting of annual crops is spread out over the seasons: therefore, in table 6 (eleven references in line 4.5 and one case in 6.1), the sowing and harvesting dates shown are the four seasons "winter, spring, summer, fall", with variable successions between them.

In a field, evergreen weeds generally coexist with other weeds with various seasonal types of vegetation (especially winter and summer plants). Chicouène (1992) has therefore elaborated a typology of calendars of emergence compared to various seasonal crop cycles. The rotation between spring and fall crops ought to affect very seasonal weeds, but should not act directly on evergreens. The latter are indirectly concerned when the control methods (e.g. mechanical stubble plowing as described by Chicouène, 2007c) show varying effectiveness depending on the seasons: so for an intercrop without plowing (see Chicouène, 2000a), mechanical stubble plowing only causes desiccation of the stolons (e.g. *Agrostis stolonifera*) in dry summers.

Intercrop management will also affect weeds that multiply mainly in winter. *Arrhenatherum bulbosum* produces corms mainly at the end of winter (in March in the northern hemisphere - see Leclerch, 1976), whether or not there is a crop in a vegetative or resting state (case of mown alfalfa mentioned by Chicouène, 2007a). Multiplication may also occur in a winter intercrop, i.e. during the season preceding a spring crop. A rotation including spring crops will only be effective if winter intercrop interventions interfere with corm formation.

A crop calendar may be cleaning for one seasonality type and dirty for another (Anderson, 2007; Chicouène, 2007a). For example with plowing, a spring crop without multiplication of winter weeds with spring reproduction and diaspores with a life span of less than a year (e.g. various annual *Bromus*) will clean for *Bromus* and multiply summer weeds, similarly, *Arrhenatherum bulbosum* corms depend on the management of the winter intercrop, production of *Calystegia sepium* rhizomes and seeds (which grow at least in any crop remaining in place for six months) depends on the management of the summer intercrop.

Crops may be planted throughout the year, but earlier or later planting dates (by just a few weeks, see table 4.1) with respect to a reference date (the optimum for a given crop) have an effect on some taxa. The latter may prove to be distinct enough from the point of view of seasonality, both in fall crops (see Colbach and Meziere, 2013) and spring crops (Chicouène, 2007a and 2016) or cover crops (Baraibar et al. 2018).

When a crop planted in a given season contributes to cleaning of weeds multiplied by a crop in another season, the number of successive cleaning-type years logically depends on the duration of the target stocks. Therefore, in a particular situation, Anderson (2007) concludes by favoring the alternation between two spring crops then two fall crops in order to control major weed species whose stocks last for approximately 12 months in the two cases of seasonal cycles.

General discussion

Cultural practices are present to a greater or lesser degree for each crop, or even between successive crops, each having more or less variability depending on the crops or the cropping plans. The aim is to strike a balance between the perspectives that they offer with respect to the flora of a field or region. They may be presented independently from one another or combined with other cultural practices or other methods of management.

Comparison of independent practices

It is easier to start by considering each practice individually, as if interactions did not exist. This approach also corresponds to the oldest documents in the supplementary file. With time, the proportion of empiricism decreases, leaving more scope for understanding the phenomena and the issue of regrouping data that at first appear to be contradictory.

Historical descriptors of cultural practices

Before the era of chemical control, the characterization of cultural types was based on categories that were not unanimously approved by the authors in the supplementary file. The resulting ideas may be summarized as follows:

- focused on a single cycle and at the same time with respect to mechanical control: hoed crops (where selective mechanical methods are most easily implemented and are generally essential for crop management) versus competitive crops (where management up to the harvest is usually possible without mechanical intervention). The notion of a "competitive crop" (Lee and Thierfelder, 2017) corresponds to a crop that should be able to cope in a dirtier field.

- specific to the organization of cultural successions, contrasting between dirty and cleaning practices.

Combining these two series, each of which has two qualifiers, should lead to several theoretical situations. As these entities remain imprecise and qualitative, or even subjective, they are at best relevant for extreme cases of crops (the expression of the quantitative aspect using "competitive ability" nonetheless appears in certain references inline 4 of table 6) and for fields with limited flora, they do not necessarily concern the entire flora in a field but only the biological groups defined for each case. Jabran and Chauhan (2018) emphasize that the "competitive crop" category corresponds to either "weed tolerance" or "weed suppression" in crops. A destructive or cleaning crop with respect to a species means both that the species is prevented from reproducing and that the species has a diaspore life span that does not exceed the crop cycle. These notions may be used to classify all the practices described. At present, due to the control methods developed during recent decades, they can aid thinking in the light of a large number of possible combinations between crop and weed descriptors, on condition that one does not restrict oneself uniquely to mechanical methods as was the case in the past. All the criteria used to classify the practices described, whatever the age of the publication in which they are described, complement one another within a scale of approach. At the same time, the two series of lists (i.e. on the one hand tables 3 to 5 and section 2.1.2, on the other hand, table 6) resemble one another: the main differences concern the greater role of the characters of cultivars within a species and the much smaller role or absence of chemical control in the first series. These lists of compiled cultural practices remain open. Except for mechanical methods that affect the soil, the practices compared are usable in no-till or soil conservation agriculture.

Descriptors of practices and descriptors of biological targets

The two lists of descriptors of cultural practices compiled from the bibliography are established for practices considered on a single cycle and for the organization of a cultural succession. The notion of the biological target that serves to describe, understand and interpret the effects of cultural practices (column D in table 7) emphasizes the following duality:

- when reasoning on a single cultural cycle, the corresponding biological targets are nearly as numerous and independent as the types of practices.

Table 7. General comparison of the issues of biological weed targets by groups of cultural methods

No	A	B	C	D	E	F
	Levels of reasoning:	Aim:	Methods-practices:	Targets: numbers, types of descriptor	Speed of action:	Limits and disadvantages:
1.	1 cultural cycle, (including mimicking weeds at the vegetative stage)	minimize harm in the coming harvest	cultural sensu stricto, sometimes includes certain other selective practices (e.g. hoeing)	numerous (28 targets in tables 3-5 = - morphological: architecture, height of organs, etc. - eco-physiological - phenological	depending on the practice, ranges from the cultural cycle, to just the harvest operation	disadvantages in about the same numbers for targets and +- opposed to the target (tables 4 and 5)
2.	temporary grassland	minimize harmfulness or the stock	height before and after an operation	few (in Chicouène 2007b), especially height of vegetation before and after operation	at least one operation cycle	selectivity reduced with respect to the crop (permanently present)
3.	mimicking weeds contaminating a batch of seeds and its cycle	minimize the populations of mimicking weeds	" harvesting conditions, sorting of harvested batches (of seeds)	morphological: shapes, dimensions, density of the diaspores	instantaneous	-
4.	cultural succession in a field: cleaning	minimize a stock of diaspores that have an effect in futures crops	c. all methods	on the 17 groups in table 6: one essential target descriptor in fig. 1 (duration of diaspores that are not renewed)	- the life span of the targeted diaspores - duration of inhibition from allelopathic after-effects	independent of the target, recolonization: - reintroduction - speed of spread
5.	a succession of practices between two crops	"	soil disinfection (without extra mixing)	1: depth of emergence with respect to the depth of disinfection	instantaneous	" + danger of deep tillage of the soil
6.	"	"	occasional plowing, not every year (without extra mixing)	2 (in Chicouène 2000a): duration of the diaspores + depth of emergence	"	"

- when considering cultural successions, in the general case (line 4 in table 7), the description of cleaning depends mainly on the life span of the stock of effective diaspores, i.e. a single descriptor. In special cases such as the introduction of a plowing operation or disinfection of the soil (respectively lines 6 and 5 in table 7), the depth of emergence is respectively the second or only descriptor.

The speeds of action of the interventions or practices (column E in table 7) are variable: the shortest is "instantaneous" (exclusive in three lines near the bottom of table 7), then they become more or less intermediate within a cultural cycle, and they may reach up to several years for the possible exhaustion of certain stocks of diaspores (depending on the practices and the type of diaspores targeted) within the limit of the duration of the rotation. In parallel to the effectiveness, problems due to the consequences on the targets and their reverse effects after several years can appear in many situations. For example, the action of some changes in soil physico-chemical properties may last for many cultural cycles. In addition, the issue of the persistence of action for the effects of a practice targeting a single cycle occurs mainly on the scale of cultural successions via the dynamics of the spread of infestations between and within fields. The management of a cycle or an intercrop also has effects on the following cycles, but only when the production or introduction of diaspores are significant with respect to the initial stock in the field and risk being difficult to control.

Levels of knowledge of the effects by practice.

Knowledge about each cultural practice can be on three possible levels:

(1)- Empirical practices, generally traditional, with an ill-defined scale of perception, which are not necessarily optimized. They often date to before the development of herbicides in the 20th century. However, recent techniques are spreading, with the rise of management without plowing, at the same time as equipment is improved in the developed countries. Agronomy textbooks generally provide little information on these cultural methods. A few investigations have been performed on some weeds in geographically limited entities, for example, certain data in Colbach et al. (2018).

(2)-The "plot level" in the classification of Lichtfouse et al. (2009) remains rare for cultural control, and, depending on the objective, the trial is carried out solely between weeds or with the accompaniment of crops, with natural or artificial contamination. Results of rotation and mulching with respect to major weeds are compared by Lee and Thierfelder (2017). To ensure later interpretations comparing weed characters, it is essential to reason by taxon or by biological group or target, not simply by the overall flora in the trial. Here are some examples:

- barley harvest at two sowing densities with the added weed *Avena fatua* in two trials by Cussan et al. (1976).

- in their trial, Drew et al. (2009) mention certain weeds that do not respond in the same way as most of the others to different parameters of crop competition (e.g. height).

(3)- The understanding of numerous biological mechanisms operating within cultural cycles. Knowledge of these, more or less precise, is likely to contribute to the adjustment or improvement of the practices originating from the two categories mentioned above. For example, Bertholdsson (2011) proposes a protocol to separate allelopathy from the competition. These interpretations serve, on the one hand, to facilitate the possible interpolations and extrapolations based on some in-depth experimental studies that have already been performed, on the other hand, to propose new trials to test original hypotheses for improving techniques.

Databases on the effects of each practice.

Possible improvements of production methods are concerned on the one hand with knowledge levels gained via experimentation, on the other hand with the creation of databases of some descriptors of weed biology (4th column in table 7, particularly diaspore survival curves and their use for choosing successions).

The mechanisms involved in the effectiveness of any cultural method may a priori be multiple:

- an indirect response to other control methods used simultaneously in the field (e.g. mechanical practices, either with limited selectivity in a hoed crop whereas they are absent in a smothering crop, or in the time interval between two crops),

- a simple physiological action (e.g. linked to the phenology of each taxon),

- interference with crops or other weeds,

- biological regulation by parasites, etc.

The different levels of information that have just been discussed are not all shown in the supplementary file or in tables 3 to 5, they may be compiled in an encyclopedic database thanks to the traceability of the bibliography. The aim is to centralize expert observations and experimental knowledge in the form of thematic databases. Mathematical modeling could be considered from the last two levels conjointly. The selection of flora in the field is a risk, as for any crop protection practice. For each practice, a distinction should be made between plants that are just spared (non-target), and the variations around an optimal cultural cycle including weeds with cycles opposed to the target (tables 4 and 5).

Accumulation and combination of cultural practices

Types of relationships in combinations of cultural practices

Combinations of cultural practices a priori lead to three types of interference: positive, neutral or negative.

- The accumulation of effectiveness of cultural practices is reported in some trials by Singh et al. (2006) and Anderson (2007) for floras reduced to a few species. In soil conservation agriculture, the effects of combinations of cultural practices are reported on a few species. And on mixed scales, i.e. on the one hand on one cycle and on the other hand on a succession, Borger et al. (2016) test closer row spaces and destruction of seeds at harvest, whereas Jabran and Chauhan (2018) consider the combination of "cover crops, mulch and rotations".

- Some combinations appear to be useless due to redundant mechanisms or actions. In particular, strict mimicking weeds are vulnerable to several interventions designed to purify crop seed batches. This is also the case for plowing following the suppression of chaff and a low-cut harvest for diaspores with emergence from shallow origins (e.g. *Bromus secalinus* a mixed mimicking weed if without plowing, or if a late spring crop follows - Chicouène, 2000a).

- Negative relationships exist for several reasons. The disadvantages of many practices (last column in tables III to V) and mechanisms of action are such that the effects cancel each other out. In other words, the two practices applied together to become ineffective. For example, the avoidance of harvest of the stock by late threshing after maturity is contrary to a cleaning rotation. Similarly, high sowing density would hardly be compatible with a tall cultivar or with heavy fertilization because of the high risk of encouraging climbing weeds (phenomenon suggested by the results on *Galium aparine* quoted by Drew et al., 2009) and then that of crop fall (which then encourages short heliophilous weeds as in the absence of a tall crop or as for a mulch).

Choice of combinations of practices in trials.

The numerous descriptors of cultural cycles multiply their possible combinations at the scale of a rotation. Even when just a few classes of states are considered for each descriptor, comparisons of the spectra of action lead to huge numbers of choices. Already, for one cycle, the implementation can differ from the phytotechnical optimum via several tens of dimensions. Data sometimes exists for pairs of practices or more. At the scale of a single cultural cycle, two descriptors are often combined, with each having several states: sowing and fertilization dates are quoted by Lee and Thierfelder (2017) in South Africa. In Iran, Koocheki et al. (2009) compare a flora of 24 taxa under three rotations with two crop-planting seasons. This operating approach is only relevant for practices without disadvantages, so for most practices, it is more complicated. In addition, due to the variable effectiveness of practices and variable targets, the alternatives are:

- either to focus on the intensity of a single practice known to be potentially very effective on the target taxon,

- or to combine several practices with the same taxonomic selectivity when each has limited effectiveness.

Understanding the mechanisms of action of each practice independently from those of other practices seems to be important when the main aim is to control the risks of combinations with negative relationships. The search for precautions when organizing combinations of interventions ought to be a priority with respect to the most harmful taxa in a field. Given the possible selections, all the flora of the field or the geographical area being considered should be taken into account. It is necessary to have at least minimal knowledge about the states of complementary biological descriptors for the flora and their various relationships with the descriptors of types of crops.

The case of meadows:

Simple choices between combinations of alternatives are illustrated by temporary grasslands because the weeds present have few cultural descriptors (2nd line in table 7 and Chicouène, 2007b). Their type of dirtying depends on vegetation heights before and after each cycle of exploitation, parameters which are themselves dependent on the production calendars. The last year is sacrificed from the point of view of diaspore production as these are easily eliminated in the following crops. In pure alfalfa in temperate climates, taxa with winter development and reproduction (strict winter weeds and short-lived evergreens) are limited by three solutions:

- either an associated crop for the winter against heliophilous weeds with slower growth than this crop,

- or control by another method (e.g. mechanical),

- or allow them to multiply and in this case, avoid fall crops after the alfalfa for a number of years that depends on the life span of the diaspores produced (i.e. at least two years with *Arrhenatherum* *bulbosum* corms). However, fall crops become possible by using alternative control methods that are not strictly cultural.

Strategies and relationships with non-cultural methods

Cultural methods in general control strategies

Control strategies can be globally organized according to the four examples compared in table 2, which are not necessarily limited to cultural methods sensu stricto. The first three, in particular, are closely linked to successions. If a cleaning strategy leads to eradication in a field, the probability of reintroduction of the taxon depends on cultural methods, but also on landscape factors for certain types of dissemination. On the other hand, exchanges from reservoirs of biological regulators outside the field should be considered on a case-by-case basis (Chicouène, 2004b). Within a field, cultural practices always exist. It is useful to understand their effects with the aim of coordinating them with the other control practices available. In integrated control, an association of different control methods in addition to cultural methods is often recommended (Anderson, 2007; Borger et al. 2016; Lee and Thierfelder, 2017; Jabran and Chauhan, 2018).

Strategic indications mainly concern a few species, with an approach that is often monospecific:

- 28 weed control textbooks out of the 51 compared by Chicouène (2013) mention the main methods usable against several dozen taxa in general, usually including the possibilities of certain cultural practices.

- Several articles describe multiyear monitoring of trials on one species to optimize certain strategies used to accompany cultural methods. Here are four examples: on *Alopecurus myosuroides,* Colbach et al. (2020), using the ALOMYSYS model, compare "crop sequence", several cultural practices sensu stricto, "optimal herbicide spraying, moldboard plowing"; on *Lolium rigidum,* Borger et al. (2016) attempt long-lasting eradication by acting on row spacing, elimination of "crop residue", herbicide use; against *Avena fatua,* Tidemann et al. (2016) show the interest of combining various methods in "Integrated Pest Management", respectively row spacing and destruction of seeds, then rotation and taking "preharvest shattering" into account; with *Phelipanche ramosa* in FLORSYS modeling, Colbach et al. (2017) combine some cultural methods sensu stricto ("sowing and harvest date, tillage”) with rotations, chemical and mechanical control. Studies by species test a small number of cultural practices and other methods each time. They rarely bring to light or explain the possible existence of taxa with opposite reactions to certain practices, or their place in the management of a set of flora. In addition, concerning the details of the overall annual species, flora in fields in limited regions, Colbach et al. (2017) and Colbach and Cordeau (2018) collect data on certain cultural practices together with other practices in the FLORSYS model and consider the probabilities of "overall high performance" for each "strategy", by discussing the "correlation between cultural practices". The prospects opened by this approach should be developed to encompass the total flora of fields using the many cultural methods summarized in table 6.

Types of interference between selectivity mechanisms

An assessment of the advantages and disadvantages of practice with respect to another having common points of taxonomic selectivity obviously goes beyond cultural methods alone, but the mechanisms demonstrated for the latter should be compared to those of other methods. The question of the global strategy against weeds in a cultural system arises for any control practice, whether cultural or not, i.e. all the practices applied or applicable in a field. In parallel, the three types of relationships discussed for the combination of cultural practices between themselves can be extended to combinations between cultural and non-cultural practices. The analysis of the mechanisms of selectivity involved will also be used to assess the advantages and risks, taking account of the inherent disadvantages of several cultural practices and the types of interaction. When targets are quoted in the literature, they are usually only taxonomic and also limited (e.g. in Singh et al., 2006). The assessment of the effects of one or several cultural practices amongst other methods appears in some monospecific studies already quoted in § 4.3.1. The relationships assessed here are mainly accumulated effectiveness. The types of interference (four groups in table 8) with non-cultural methods may vary according to the practices when considered in pairs, and according to their targets and counter-targets. In short, it is at the scale of a sufficiently large phytogeographical zone that substitutions of methods should be analyzed, and on a sufficiently long time scale to exclude possible ephemeral correlations between the effects of a crop and the effects of the herbicides used on it during the years of study.

Negative interferences between cultural and other methods may occur in both directions, depending on the chronology of the actions:

- direct: for example, mechanical interventions that deeply work the soil will more or less cancel out the effects of methods that provide surface cleaning for species emerging close to the surface that still have deeply buried viable diaspores.

- indirect: some cultural methods could disturb pre-existing biological regulations. Their action is often considered to be complex since Pammel (1911) and difficult to predict (Upadhyaya et al., 2007: 27). This risk of negative interactions requires knowledge of the mechanisms of action of each cultural practice. If it acts via a biological regulation, it could be disturbed by another cultural intervention. The assessment of its conditions of effectiveness should aid the choice of when to take them into account.

Table 8. A priori examples of types of interference between cultural and other practices

Type	cultural sensu stricto	rotation
interference impossible (incompatible practices)	mechanical p.p. (e.g. living permanent ground cover with respect to plowing when planting the crop)	mechanical p.p. (e.g. living permanent ground cover with respect to stubble plowing between 2 crops)
only negative	–	breaks the biological regulation within the field
all types (-, 0, +)	biological + landscape (open could sometimes encourage the introduction of auxiliaries)	landscape (open encourages the introduction of some weeds)
without direct interference (possible complementarity by substitution of taxonomic spectrum)	chemical (may allow avoidance of dilemmas of cultural practices with two extreme states with taxonomic selectivity that is partly common)	chemical (often increases the taxonomic spectrum of cleaning)

Comparison of descriptors between cultural and other methods

The multiple mechanisms and biological targets of cultural methods are more complex to understand than those of uniquely mechanical methods. The latter is reduced to a few general principles, mainly architectural, outlined by Chicouène (2007c) on the basis of two main and opposed mechanisms (exhaustion of energy reserves as opposed to desiccation). The actions of plowing with respect to biological forms and soil and climatic conditions are shown by Chicouène (2000a). Two types of extreme targets are described by their architecture (depths of formation and emergence), i.e. limiting of stoloniferous weeds in the dampest and most asphyxiating conditions, deep underground organs regrowing elsewhere. These comparisons between the architectural descriptors of two types of traditional methods connect two extreme types via several descriptors, at least in temperate climates (Chicouène, 2000a, 2007a and b, 2016):

- short stoloniferous heliophilous weeds, which are advantaged by damp soil and climate conditions and by low-growing crops or intercrops. These are difficult to control by stubble plowing, but limited by plowing,

- tall vigorous weeds, with emergence from deep origins (diaspores with substantial energy reserves), in deep healthy soils, which are capable of growing through a layer of ploughed soil as well as a layer of dead mulch, or even a tall cultural ground cover.

Thus, numerous parameters of foliage and depth of emergence become common descriptors for the implementation of several groups of control methods: in addition to cultural methods, they are used a lot for other methods, at least for mechanical and chemical control. For all the strategies, population forecasts according to the biological diversity of the diaspores (Chicouène, 2004a) are a crucial step for decisions concerning cultural practices and several other types of practice. A database of weed biology destined for dirtying forecasts and cultural control could be useful for the combination with other management methods, especially in view of the fact that many descriptors simultaneously determine several methods. The logical idea would be to contribute to the coordination with other methods by comparing the targets. As far as landscape factors are concerned, these intervene directly by the transfer of weeds between fields, particularly mimicking weeds and easily cleaned weeds (Chicouène, 2004b) and indirectly on the source of biological regulation. In parallel, the subject of the exploitable level of population for biological regulation is primordial: while its effectiveness is sometimes proportional to the density of the taxon (e.g. Westerman et al., 2008; Baraibar et al., 2011), then this phenomenon, when it is effective on certain species, is likely to call into question classical notions of cleaning that aim to minimize stocks of diaspores rather than harmfulness, or even the search for added effectiveness. These relationships, which can also be exploited for the management of biodiversity, are an indispensable theme for models of sustainable agriculture or agroecology. This would be a complement to the "multiobjective" approach of Colbach et al. (2017b and 2017c) on biodiversity.

Conclusion

The cultural methods listed are organized from references which each have a number and a variable classification of practices, they all group together criteria of choice of cultivated species or cultivars and management of fields and their successions. Finally, they are shown at two distinct scales of issues. In one, there is no absolute limit with other types of control methods: this is the strategy in the succession of management of cultural cycles (all control methods considered), generally over several years, in other words, it is the way in which the different practices are made to follow one another in successive crops that defines the character of cultural control. In the other scale, when taken strictly, i.e. considering a single crop cycle, cultural methods do not encompass the other control methods, with the possible exception of a biological regulation that would depend on them, or even (at the limit) on selective mechanical interventions allowed in some crops. The particularity of most of the many practices of cultural control is the risk that they may encourage weeds opposite to the target. This widespread duality justifies two consequences:

On the one hand, the aim is to avoid the case where a protocol with a global assessment concerning all weeds, without identification, would logically lead to an opposite conclusion when this flora corresponds to an opposite biological target. Proper exploitation of studies on cultural practices absolutely requires presentation of the results for known biological targets (or they could at least consider later by means of detailed results by taxon).

- On the other hand, databases on biological descriptors of the flora need to be adapted sufficiently to ensure the employment of notions that are more finely tuned than a simple balance between immediate benefit and cost.

For some biological forms, effectiveness may possibly be proportional to the intensity of the efforts around the phytotechnical optimum of a crop, a cropping plan or a cultural system. In order to best identify the issues involved, practices whose mechanisms of action rely uniquely on hypotheses with little documented evidence should be clarified, particularly as concerns the quantitative relationship between an essential descriptor and the corresponding target.

The most important biological descriptors of targets require a consensus, but one difficulty is that some recent syntheses on cultural methods do not mention knowledge recognized in older weed science documents. Excluding such ambiguities and the necessity to rehabilitate some knowledge, the explanation of the diversity of all existing cultural methods highlights the wide range of possibilities available. Strictly speaking, the lists of targets defined by practice should be considered in the operation of agricultural systems. This is a step towards improved technical expertise, logically as for any method of flora management.

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Conflicts of Interest

No conflict of interests has been declared

References

Abouziena H.F, Haggag W.M. 2016. Weed Control in Clean Agriculture: A Review. Planta daninha. 34: 2

Ahlgren G.H, Klingman G.C, Wolf D.E. 1951. Principles of Weed Control. J. Wiley, New York., 368 p.

Albuquerque M, Dos Santos R.C, Lima L.M, Melo Filho P, Nogueira R.J.M.C, Da Camara C.A.G, Ramos A.R. 2011. Allelopathy, an alternative tool to improve cropping systems. A review. Agronomy Sust. Dev. 31(2): 379-395.

Aldrich R.J, Kremer R.J. 1997. Principles of weed management. Second edition, Panima Publishing Corporation, New Delhi, 455 p.

Altieri M.A, Liebman M. 1988. Weed management in agroecosystems: ecological approaches. CRC Press, U.S. 354 p.

Anderson W.P. 1983. Weed science : principles. West Publishing Company, ed. 2, 655 p.

Anderson R.L. 2007. Managing weeds with a dualistic approach of prevention and control. Agron. Sustain. Dev. 27: 13-18.

Andrade J.F, Satorre E.H, Ermacora C.M, Poggio S.L. 2017. Weed communities respond to changes in the diversity of crop sequence composition and double cropping. Weed Res. 57: 148-158.

Baraibar B, Daedlow D, De Mol F, Gerowitt B. 2012. Density dependence of weed seed predation by invertebrates and vertebrates in winter wheat. Weed Res. 52: 79-87.

Baraibar B, Hunter M.C, Schipanski M.E, Hamilton A, Mortensen D.A. 2017. Weed Suppression in Cover Crop Monocultures and Mixtures. Weed Sci. 66: 121-133.

Baraibar B, Mortensen D.A, Hunter M.C, Barbercheck M.E, Kaye J.P, Finney D.M, Curran W.S, Bunchek J, White C.M. 2018. Growing degree days and cover crop type explain weed biomass in winter cover crops. Agronomy Sustain. Dev. 38: 65.

Barrett S.C.H. 1983. Crop mimicry in weeds. Economic Botany. 37(3): 255-282.

Bertholdsson N.O. 2011. Use of multivariate statistics to separate allelopathic and competitive factors influencing weed suppression ability in winter wheat. Weed Res. 51: 273-283.

Bolley H.L. 1908. Weeds and methods of eradication: weed control by means of chemical sprays. North Dakota Agricultural College, pp. 507-574.

Brenchley W.E. 1920. Weeds of farm land. Longman, Green and Co., London. 239 p.

Borger C.P.D, Riethmuller G, D'Antuono M. 2016. Eleven years of integrated weed management: long term impacts of row spacing and harvest weed seed destruction on *Lolium rigidum* control. Weed Res. 56: 359-366.

Buhler D.D. 1999. Expanding the context of weed management. Food Products Press, NY, 289 p.

Chancellor R.J. 1964. Emergence of weed seedlings in the field and the effects of different frequencies of cultivation. *Proc.* 7th Br. Weed Control Conf*.* 599-606

Chaudary S, Kumar D, Sharma R, Rathi J.P.S. 2011. Weed management, principles and practices. Narendra Publishing House, Delhi, 207 p.

Chicouène D. 1996. Typologie des périodes de levée des mauvaises herbes à partir d'organes végétatifs sous climat tempéré océanique. *Xè Colloque Intern. Bio. Mauvaises Herbes. Dijon, Association Nationale de Protection des Plantes*, 7-15.

Chicouène D. 2000a. Effets de la suppression du labour sur les mauvaises herbes en climat tempéré océanique. *XIth International Conference on Weed Biology, Dijon*, 425-435.

Chicouène D. 2000b. Stratégies de lutte contre les mauvaises herbes : préventives ou curatives ? I. Aperçu des bases de raisonnement. *Phytoma - La Défense des Végétaux* 532: 12-16.

Chicouène D. 2004a. Descripteurs biologiques des diaspores de mauvaises herbes pour les prévisions du peuplement infestant une parcelle. *XIIth International Conference on Weed Biology*, Dijon 31 août - 2 septembre 2004: 355-362.

Chicouène D. 2004b. Le rôle du bocage dans la réduction de la dissémination entre parcelles des mauvaises herbes des cultures. *Ingénieries : Eau, Agriculture, Territoires* 38 : 47-59.

Chicouène D. 2006. Le raisonnement des successions culturales : I. Caractérisation préalable des populations d'ennemis. Association Française de Protection des Plantes – Third International Conference on Non-Chemical Crop protection Methods, Lille, France, 13, 14 and 15 March 2006, 424-433.

Chicouène D. 2007a. Mauvaises herbes, utiliser la rotation ? Prise en compte de la phénologie des mauvaises herbes pour les combattre dans la rotation : généralités et exemples de cinq espèces sous climat tempéré océanique. *Phytoma - La Défense des Végétaux* 600: 32-36.

Chicouène D. 2007b. Biologie des principales mauvaises herbes des prairies temporaires du Massif Armoricain. Conséquences pour la gestion prairiale. *Fourrages* 190 (2007): 251-260.

Chicouène D. 2007c. Mechanical destruction of weeds. A review. *Agron. Sustain. Dev.* 27: 19-27.

Chicouène D. 2009. Typologie des sélectivités des principales méthodes de lutte contre les mauvaises herbes. *XIIIth International Conference on Weed Biology*, Association Française de Protection des Plantes, Dijon, september 8-10 2009: 106-116.

Chicouène D. 2010. Principaux types de nuisibilité des mauvaises herbes dans les grandes cultures tempérées. AFPP - 21nd COLUMA Conference, International Meeting on Weed Control, Dijon - December 8-9, 2010. 120-129.

Chicouène D. 2013. *Weed control approaches in 51 weed science handbooks.* 22nd COLUMA Conference, International Meeting on Weed Control, Dijon - December 10, 11 & 12 2013.

Chicouène D. 2016. Cibles biologiques de 26 méthodes culturales de lutte contre les mauvaises herbes dans le cycle d'une culture. AFPP - 23nd COLUMA Conference, International Meeting on Weed Control, Dijon : 80-90.

Colbach N, Chauvel B, Gauvrit C, Munier Jolain N. 2007. Construction and evaluation of ALOMYSYS modelling the effects of cropping systems on the blackgrass life-cycle: From seedling to seed production. Ecological Modelling. 201 (3-4): 283-300.

Colbach N, Schneider A, Ballot R, Vivier C. 2010. Diversifying cereal-based rotations to improve weed control. Evaluation with the ALOMYSYS model quantifying the effect of cropping systems on a grass weed. OCL Oléagineux Corps Gras Lipides. 17(5): 292-300.

Colbach N, Meziere D. 2013. Using a sensitivity analysis of a weed dynamics model to develop sustainable cropping systems. I. Annual interactions beween crop management techniques and biophysical field state variables. J Agric Sci. 151: 229-245.

Colbach N, Bockstaller C, Colas F, Gibot-Leclerc S, Moreau D, Pointurier O, Villerd J. 2017a. Assessing broomrape risk due to weeds in cropping systems with an indicator linked to a simulation model. Ecol Indicators. 82: 280-292.

Colbach N, Darmency H, Fernier A, Granger S, Le Correv V, Messean A. 2017B. Simulating changes in cropping practices in conventional and glyphosate-resistant maize. II. Weed impacts on crop production and biodiversity. Environ. Sci. Pollut. Res. 24: 13121-13133.

Colbach N, Colas F, Pointurier O, Queyrel W, Villerd J. 2017c. A methodology for multi-objective cropping system design based on simulations. Application to weed management. Eur J Agron. 87: 59-73.

Colbach N, Cordeau S. 2018. Reduced herbicide use does not increase crop yield loss if it is compensated by alternative preventive and curative measures. Eur J Agron. 94: 67-78.

Craft A.S. 1975. Modern weed control. University of California Press, 440 p.

Cussans G.W. 1976. Cultural control. *In* Wilds oats in world agriculture. JONES D.P. ed. Agricultural Research Concil, London, 127-142.

Drew S, Neuhoff D, Kopke U. 2009. Weed suppression ability of three winter wheat varieties at different row spacing under organic farming conditions. Weed Res. 49: 526-533.

Evers J.B, Bastiaans L. 2016. Quantifying the effect of crop spatial arrangement on weed suppression using functional-structural plant modelling. J Plant Res. 129: 339-351.

F.A.O. 1986. Instructor's manual for weed management. International Plant Protection Center, Rome, 149 p.

Froud-Williams R.J, Chancellor R.J, Drennan D.S.H. 1984. The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation. J Appl Ecol. 21(2): 629-641.

Fryer J.D, Matsunaka S. 1977. Integrated control of weeds. University of Tokyo press, Japan, 262 p.

Gupta O.P. 2007. Fundamentals of weed science. Agrobios, India, 379 p.

Gwynne D.C, Murray R.B. 1985. Weed biology and control in agriculture and horticulture. Batsford, London, 258 p.

Hatcher P.E, Froud-Williams R.J. 2017. Weed Research: Expanding Horizons. Wiley. 256 p.

Inderjit. 2004. Weed biology and management. Kluwer Academic Publishers, The Netherlands, 553 p.

International Plant Protection Center. 1986. Instructor's manual for weed management. F.A.O., Rome, 149 p.

Kadioglu I, Yanar Y. 2004. Allelopathic Effects of Plant Extracts Against Seed Germination of Some Weeds. Asian J Plant Sci. 3: 472-475.

Jabran K, Chauhan B.S. 2018. Non chemical weed control. Academic Press, India. 161 p.

Hakansson S. 2003. Weeds and weed management on arable land : an ecological approach. CABI, UK, 274 p.

King L.J. 1966. Weeds of the world, biology and control. Hill, London, 526 p.

Klingman G.C, Ashton F.M, Noordhoff L.J. 1982. Weed control: principles and practices. Wiley, New York, London, 2 ed. 449 p.

Kone B, Traore K, Toure A. 2014. Basal Fertilizer Effects on Weed Occurrence and Rice Yield in Acid Upland Soil of West Africa at Bénin. J Plant Sci. 2: 14-22.

Koocheki A, Nassiri M, Alimoradi L, Ghorbani R. 2009. Effect of cropping systems and crop rotations on weeds. Agron. Sustain. Dev. 29: 401-408.

Korres N.E, Froud-Williams R.J. 2002. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occuring weed flora. Weed Res. 42: 417-428.

Labrada R, Caseley J.C, Parker C. 1994. Weed management for developing countries. FAO, 384 p.

Le Clerch J. 1976. La biologie de l'Avoine à chapelet *Arrhenatherum elatius* (L.) Mert. and K. var *bulbosum* (Willd.) Spenn. Vè Colloque Intern. Ecol. Bio Mauvaises Herbes, A.N.P.P. 343-350

Lee N, Thierfelder C. 2017. Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. Agron. Sustain. Dev. 37: 2-25.

Lichtfouse E, Navarrete M, Debaeke P, Souchere V, Alberola C, Menassieu J. 2009. Agronomy for sustainable agriculture. A review. Agron. Sustain. Dev. 29: 1-6.

Liebman M, Mohler C.L, Staver C.P. 2001. Ecological management of agricultural weeds. Cambridge University Press, 534 p.

Long H.C, Percival J. 1910. Common weeds of the farm & garden. Stokes Company, New York, 451 p.

Malézieux E.M, Crozat Y, Dupraz C, Laurans M, Makovsaky D, Ozier-Lafontaine H, Rapidel B, de Tourdonnet S, Valentin-Morison M. 2009. Mixing plant species in cropping systems: concepts, tools and models. A review. Agron. Sustain. Dev. 29: 43-62

Martin J, Le Bourgeois T, Lebreton G, Marnotte P, Esther J.J, Chabalier M, Valéry A, Lépinay E. 2012. Pourquoi tant de lianes ? Le cas de la canne à sucre à La Réunion. Congrès sucrier ARTAS / AFCAS 2012, La Réunion. 10-14/09/2012 Saint-Gilles La Réunion. 10 p.

McElroy J.S. 2014. Vavilovian Mimicry: Nikolai Vavilov and His Little-Known Impact on Weed Science. Weed Sci. 62: 207-216.

Monaco T.J, Weller S.C, Ashton F.M. 2002. Weed science, principles and practices. John Wiley and sons, New York, 4e ed., 671 p.

Muenscher W.C. 1936. Weeds. Macmillan Company, New York, 577 p.

Muzik T.J. 1970. Weed biology and control. McGraw-Hill book company, New York, 273 p.

Naylor R.E.L. 2002. Weed management handbook. British Crop Protection Council, 9th ed., Blackwell, Oxford, 423 p.

Pammel L.H. 1911. Weeds of the farm and garden. Orange Judd Company, New York, XI + 281 p.

Pawar R.K. 2009. Weed management. Jaipur, India, 300 p.

Poggio S.L. 2005. Structure of weed communities occuring in monoculture and intercropping of field pea and barley. Agric. Ecosyst. Environ. 74: 19-31.

Radosevich S.R, Holt J.S, Ghersa C. 1997. Weed ecology, implications for vegetation management. John Wiley and sons, New York, ed. 2, 589 p.

Ramamoorthy K, Subbian P. 2006. Weed management. Agrotech Books, 560 p.

Ramexh K. 2015. Weed problems, ecology, and management options in conservation agriculture: issues and perspectives. Adv Agron. 131: 251-303.

Robins W.W, Crafts A.S, Raynor R.N. 1942. Weed control, a textbook and manual. McGraw-Hill book company, New York and London, 542 p.

Ross M, Lembi C.A. 1985. Applied weed science. Macmillan, U.S. 340 p.

Saraswat V.N. 2003. Weed management. Indian Council of Agriculture, New Delhi, 327 p.

Shaw T. 1892. Weeds and modes of destroying them. Ontario Agricultural College, Bulletin LXXXV, Toronto, 31 p.

Shaw T. 1893. Weeds and how to eradicate them. Bryant, Toronto, ed. 1, 210 p.

Singh H.P, Batish D. 2006. Handbook of sustainable weed management. Food Products Press, 892 p.

Smith A.E. 1995. Handbook of weed management systems. Dekker, New York, 741 p.

Soufan R, Almouemar A. 2009. Allelopathic effects of some weeds on growth of maize (*Zea mays* L.). XIIIth International Conference on Weed Biology, Dijon, september 8-10, 414-421.

Stephens R.J. 1982. Theory and practice of weed control. Macmillan, Royal Horticultural Society, 215 p.

Subramanian S, Mohamed Ali A, Jaya Kumar R, Muthukrishnan P, Vallal Kannan S, Chandrasekaran B. 2011. All about weed control. Kalyani Publishers, Ludhianana, ed.2 (second revised & enlarged edition), 321 p.

Tidemann B.D, Hall L.M, Neil Harker K, Alexander B.C.S. 2017. Identifying Critical Control Points in the Wild Oat (*Avena fatua*) Life Cycle and the Potential Effects of Harvest Weed-Seed Control. Weed Sci. 64: 463-473.

Upadyaya M.K, Blackshaw R.E. 2007. Non Chemical Weed Management Principles, Concepts and Technology. University of British Columbia, Canada, R E Blackshaw, Agriculture and Agri-Food Canada, 240 p.

Walia U.S. 2010. Weed management. Kalyani Publishers, India, ed.3, 373 p.

Westermann P.R, Borza J.K, Andielkovic J, Danielson B. 2008. Density-dependent predation of weed seeds in maize fields. J Appl Ecol. 45: 1612-1620.

Wortman S.E. 2016. Weedy fallow as an alternative strategy for reducing nitrogen loss from annual cropping systems. Agron Sustain Develop. 34(4): 1-10.

Zimdahl R.L. 1993. Fundamental of weed science. Academic Press, San Diego, 450 p.

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