Comparative sustainability assessment of the impact of GM plants in Swiss conventional, integrated and organic farming systems. A project funded by NRP 59.

Agronomic consequences of the use of GM crops. Part 1: arable crops

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Workpackage 3

Description in project proposal (p. 23): «Workpackages 3-5 will assess the impact of the production system scenarios on (i) agronomy, (ii) biodiversity and agro-ecology and (iii) socio-economics at the farm and the regional level. Baseline and alternative scenarios will subsequently be submitted to a comparative technology impact assessment. The assessment will include changes in agronomic parameters, expected differences in yield, quality and input usage (e.g. land use, pesticide use etc.). The potential environmental benefits of GM plants will be assessed, with a special focus on pesticide use, crop yields, weed control, soil tillage and soil protection. The environmental risk assessment will take the impact on biodiversity and the soil ecosystem into account.

The central assessment tool in workpackages 3-5 will consist of semi-quantitative assessment matrices. The proposed comparative sustainability assessment matrix is a combination of the Swiss approach to assess sustainability of agriculture (BLW Agrarbericht 2005, ARE Nachhaltigkeitsbeurteilung) and the CSA-Matrix method proposed by ACRE (2006). The detailed criteria and parameters will be prepared during the project by the project leader and refined by the competence teams in workshop 3. The overall baseline for comparison is the state-of-the-art integrated production with good agricultural practice.»

Document history: This report was prepared by the competence team «farming systems».

The general agronomic consequences of the use of GM crops were outlined in workshop 3 on 1 – 2 October 2008. In workshop 5 on 3 – 4 June 2009, agronomic practices and consequences were discussed in detail for arable crops. This report was prepared after workshop 5 and circulated to all participants for comments. On September 14, Jan Lucht from Internutrition pointed out some inconsistencies regarding the fungicide treatments of GM potatoes. Sections 3.4 and 4.1 were amended subsequently. In workshop 6, it was noted that some rotations do not comply with ÖLN production rules and must therefore be considered as conventional. It was decided to include a rotation with maize only (see section 4.5), and to include micronutrient fertilization in those GM crops which are treated with glyphosate, to make sure that the phenomenon is not overlooked in the assessments (see section 3.3). On September 21, Andreas Keiser from SHL Zollikofen informed us that according to his investigations, the average number of fungicide applications in potatoes in Switzerland is 8; section 4.1 was amended accordingly.

Contents

1 Introduction

This document is prepared as a project-internal tool. It assesses the agronomic consequences of the use of GM crops in selected Swiss agricultural systems (arable crop rotations). The GM crops are described in detail in the document «List of GM plants and traits». The agricultural systems and conditions were outlined in an earlier workshop, and described in the document «Model farms and scenarios». In that report, it is also shown how the crop rotations were developed from the baseline rotation in the DOC trial. In workshop 5, minor modifications of the crop rotations were made (see figure 1). The Main bottlenecks in arable production are also described in the document «Model farms and scenarios».

2 General assumptions for the scenarios

The following general assumptions were made or confirmed during workshop 5:

The model farm is located in the Swiss «Mittelland» region and has a total size of 40 ha. The integrated model farm may be a mixed or a stockless farm, while the organic farm is assumed to be a mixed farm. In the cultivation of cereals, the integrated farm does not follow the «Extenso» programme.

For the economic calculations, the model developed during the 'Sigmea' project will be developed further. Market acceptance and problems of co-existence between GM and GM-free production are excluded from the analyses. To estimate costs of GM varieties, experiences from the USA and Europe will be used. Prices for GM products are assumed to be identical to those for non-GM products. Unlike in the USA, GM foods must be labelled in Europe and Switzerland, therefore labelling costs will be included in the model.

2.1 Note on conventional rotations

When the model farms and scenarios were defined, it was agreed that for economic reasons, the non-organic farms would aim at receiving direct payments under the ÖLN scheme. During WS 6, it became evident that the ÖLN production rules allow very little flexibility for designing novel crop rotations which would take advantage of the novel traits of GM crops. In order to explore the full range of possible impacts of GM crops, it was therefore decided to include also rotations which do not comply with the present ÖLN production rules. These are called «conventional rotations».

The maximum proportions of main crops are specified in Annex 4.2 of the 'Direktzahlungsverordnung'[1]. The reasons for classifying some rotations as «conventional» are the following:

CONV-mixed: the proportion of maize is 66 % (maximum: 40 %)

CONV-stockless: the proportion of wheat is 66 % (maximum: 50 %);
the proportion of sugar beets is 33 % (maximum: 25 %)

CONV-maize: the proportion of maize is 100 % (maximum: 40 %)

[1] Verordnung über die Direktzahlungen an die Landwirtschaft (Direktzahlungsverordnung, DZV). SR 913.13

3 General assumptions regarding GM crops and their cultivation

3.1 Tillage systems

Minimum tillage is already frequent in Switzerland today, and will become even more frequent within the next decade. By contrast, direct drilling is rare, and only practices by a few leading farmers who are able to manage the weed problems associated with this practice.

The non-GM scenarios (integrated and organic) are based on minimum tillage. In the GM scenarios, integrated farms are assumed to change to direct drilling, while organic farmers will continue minimum tillage (in organic farming, no herbicides are allowed).

3.2 Weed problems and volunteer plants

Volunteer plants of oilseed rape, wheat and sugar beet may act as weeds in the following crop. If herbicide tolerant rape, wheat or sugar beet are grown, appropriate measures must therefore be taken in the rotation to avoid weed problems («herbicide rotation»).

In maize and soy, volunteer plants do not constitute a weed problem. In potato, volunteers do not constitute a weed problem, but may enhance the late blight epidemic. However, the ideotype GM potato is not assumed to be herbicide tolerant, therefore this aspect remains unchanged between GM and non-GM scenarios.

Transfer of herbicide tolerance (ht) to weed species: ht may be transferred to related wild species directly, or indirectly via «botanical bridges». The experts assume that ht transfer is possible from oilseed rape to all wild crucifers (note: experiences from the USA cannot be transferred to Europe, because wild crucifer species are much more numerous in Europe than in the USA). In the case of wheat, ht transfer is possible from wheat to one wild species, *Aegylops cylindrica*, which occurs in the canton Valais. Sugar beets can cross out with other *Beta spp*., but not with the weeds *Chenopodium spp*. (A. Schori, ACW, pers. communication). Thus, the risk of transfer of ht from GM sugar beets to weeds is unclear. For maize and soy, the experts do not see a risk of ht transfer.

3.3 Micronutrients

Experience from the USA demonstrates that GM soy and maize treated with glyphosate is often deficient in micronutrients, especially manganese and needs additional micronutrient fertilization. Recently, it was observed that herbicide treated soy needs more fungicides than conventional crops, possibly as a consequence of manganese deficiency (Huber, 2006; Huber, 2007a).

To prevent micronutrient deficiency, GM crops treated with glyphosate should receive additional micronutrients. Best results are obtained with a foliar treatment ca 15 days after the glyphosate application (Huber, 2007b).

The experts do not know to what extent such phenomena will also occur in other GM crops. In WS 6 it was decided to include a micronutrient fertilization after each aaplication of glyphosate to a GM crop. This ensures that the phenomenon is not

overlooked in the assessments. Whether it will actually occur in all GM crops is unknown at the moment.

3.4 Resistance management and interactions with pests and diseases

Maize, root worm: In the USA, growers of bt maize containing a resistance against the corn rootworm *(Diabrotica vigifera)* have to sing *a* «Grower agreement» which specifies that they must adhere to the refuge requirements of the Environmental Protection Agency (EPA). Specifically, growers must plant a structured refuge of at least 20 % non-cry3Bb1 maize, which may be treated with insecticides as needed to control corn rootworm larvae. By contrast, growers are not permitted to apply corn rootworm labelled insecticides to the refuge while adult corn rootworms are present, unless the field of cry3Bb1 maize is treated in a similar manner. Refuges should be planted as blocks adjacent to cry3Bb1 maize fields or as in-field strips.

Maize, corn borer: As part of the purchase contract, all growers of bt-maize are required to follow a resistance management strategy. In order to maintain a population of bt-sensitive corn borers, at least 20 % of the maize must not contain bt genes. The non-bt maize can be grown within the field, or in another field which is not more than 750 m away from the bt-maize (Anonymous, 2007). In the GM scenarios, it will therefore be assumed that 80 % of the total surface of maize will be planted with a variety resistant to the target pests, while 20 % are planted with a susceptible variety. The pest susceptible variety will also be a GMO variety, which is herbicide tolerant. In order to maintain a high pest population, this variety will not be treated against corn borers (insecticides or *Trichogramma*), and will therefore suffer yield losses due to the corn borer.

Maize, *Fusarium*: Bt maize has less feeding damage on leaves and stems (absence of corn borer attacks). It is discussed whether this reduces the possibilities for *Fusarium* infection (Horstmann and Schaare, 2007). On the other hand, minimum tillage and direct drilling have been shown to increase *Fusarium* infection in various crops (Bateman *et al.*, 2007; Fernandez *et al.*, 2007). Because of these uncertainties, *Fusarium* pressure is assumed to equal in GM and non-GM varieties. This is consistent with the findings of (Magg, 2004).

Potatoes, late blight: R genes from potato cultivars have been used in classical potato breeding, but in many cases, the resulting resistance against late blight was not durable (e.g. (Flier *et al.*, 2007)). In GM breeding, R genes from resistant wild species (*Solanum bulbocastanum*) are used. Whether this approach results in more durable resistance is unclear at the moment. Given the experience from classical breeding, a resistance management strategy involving some fungicide applications against *Phytophthora infestans* is realistic. In addition, there are also other potato diseases (mainly *Alternaria solani*) which are normally controlled as a side-effect of the fungicide applications against *Phytophthora infestans*. Therefore, some fungicide treatments will be retained.

Potatoes, potato beetle: In the USA, resistance management for Bt potatoes is mandatory and growers are already signing contracts which included a refuge requirement. The resistance management is based on rotation of resistant and susceptible potato varieties, and on refuges with susceptible potatoes. Specific grower recommendations are as follows[2]:

[2] http://www.epa.gov/oppbppd1/biopesticides/pips/bt_brad2/4-irm.pdf

1. Do not plant your entire potato acreage with «NewLeaf» potato varieties, but maintain at least 20 % of the total acreage as refuge.
2. Do not use a foliar Bt application for the control of potato beetles on refuge acres. You may treat potato beetles in the refuge with other insecticides to prevent damage. It is recommended that you use foliar insecticides only when populations reach damaging levels, according to local IPM recommendations.
3. Plant every NewLeaf potato field within ½ mile or less of the appropriate current year refuge or Plant every NewLeaf potato field within ½ mile of land that was the designated refuge (non-Bt potatoes) last year.
4. Use of every method available to reduce potato beetle populations such as crop rotation, propane flaming, trench trapping, and overwintering habitat destruction.

Potatoes, nematodes: The experts do not know of strategy for resistance management against nematodes. However, they assume that some kind of resistance management strategy would be needed, if such varieties are grown on a large scale.

Herbicide tolerance: see section 3.5.

3.5 Alternating tolerance to herbicides

The GM ideotypes (except GM potatoes) are assumed to be tolerant against either glyphosate or glufosinate.

In order to avoid weed problems with herbicide tolerant volunteer plants or with wild plants which have become herbicide tolerant through gene transfer, glyphosate and glufosinate have to be alternated («herbicide rotation»). This is relevant for oilseed rape, wheat and sugar beet.

In WS 6, it was decided to model rotations with wheat resistant to glyphosate, and with maize, rape and sugar beet resistant to glufosinate. This results in a fairly regular alternation of herbicide tolerances during the crop rotation (table 1). Only in rotation CONV-maize, tolerances to glyphosate and to glufosinate must be altered within the same crop (maize).

3.7 Additional labour

As part of the «Grower agreement», farmers who plan to cultivate GM crops have to attend a training course. The course is free of charge, but the farmer has to find time to attend it. Farmers who grow Ht crops are required to carry out field inspections to detect potential herbicide tolerant weeds.

Table 1: Sequence of GM crops resistant to glyphosate and to glufosinate in the integrated and the conventional rotations. The organic rotations are not shown, because herbicides must not be used in organic farming.

Rotation	Tolerant to
INT-potatoes	
GM winter wheat 1	glyphosate
GM potatoes	-
GM winter wheat 2	glyphosate
GM maize	glufosinate
INT-rape	
GM winter wheat 1	glyphosate
GM rape	glufosinate
GM winter wheat 2	glyphosate
GM maize	glufosinate
CONV-mixed	
GM maize	glufosinate
GM maize	glufosinate
GM winter wheat	glyphosate
CONV-stockless	
GM winter wheat 1	glyphosate
GM winter wheat 2	glyphosate
sugar beet	glufosinate
CONV-maize	
GM maize	glyphosate (year 1) / glufosinate (year 2)

3.8 Yield potential[3]

For some crops, it has been shown that genetic modification and the resulting resistance carries a physiological cost (e.g. soy, (Anonymous, 2009); wheat (S. Zeller, Univ. Zürich, unpublished data). Accorcing to (Brookes and Barfoot, 2005), some GM crops have higher yield as the corresponding conventional crops, while others have equal yields. Because there are no clear data, the yield potential of GM varieties with pest resistance or herbicide tolerance is assumed to be identical to comparable, conventional varieties without these traits.

3.9 Assumptions for yield and fertilization

In the scenarios for integrated farming, the reference yields from «GRUDAF 2009» (Grundlagen für die Düngung im Acker- und Futterbau) will be used (Flisch *et al.*, 2009). Fertilization levels will be adjusted to the GRUDAF norms (see table 2). Manure and slurry is assumed to come from cattle kept in loose housing. For their nutrient content see table 3.

In the scenarios for organic farming, yields and fertilization will follow the experience from the DOC trial (baseline) (Table 2, last column). Fertilization is done mainly with manure and slurry, and commercial fertilizers are only used as supplements (K fertilizers and N fertilizers in potatoes).

[3] yield potential is the yield level which can be achieved under optimal conditions (good growing conditions, absence of pests and diseases)

Table 2: Yield (in dt/ha) and fertilization levels (in kg/ha) in the integrated systems. Values for the integrated system are based on GRUDAF; values for the organic system are based on the DOC trial. Crops are in the same order as in GRUDAF.

Crops	Integrated system					organic system
	Yield	N	P_2O_5	K_2O	Mg	Yield
winter wheat	60	140	60	100	15	50
maize (for sileage)	175	110	80	220	25	160
potatoes	450	120	70	375	20	250
sugar beet	750	100	85	465	70	525
oilseed rape	35	140	65	110	15	25
soy	30	0	70	120	15	30
green manure	25	0	0	0	0	21
catch crop	25	30	25	90	10	21
grass – clover (5 cuts)	115	140	90	275	35	100

Table 3: Nutrient content of organic fertilizers (in kg/t or kg/m^3). Source: GRUDAF.

Organic fertilizer	Type in GRUDAF	$N_{available}$	P_2O_5	K_2O	Mg
Manure	Laufstallmist	1.9	2.2	10.8	0.7
Slurry	Gülle kotarm	3.9	1.2	11.6	0.5

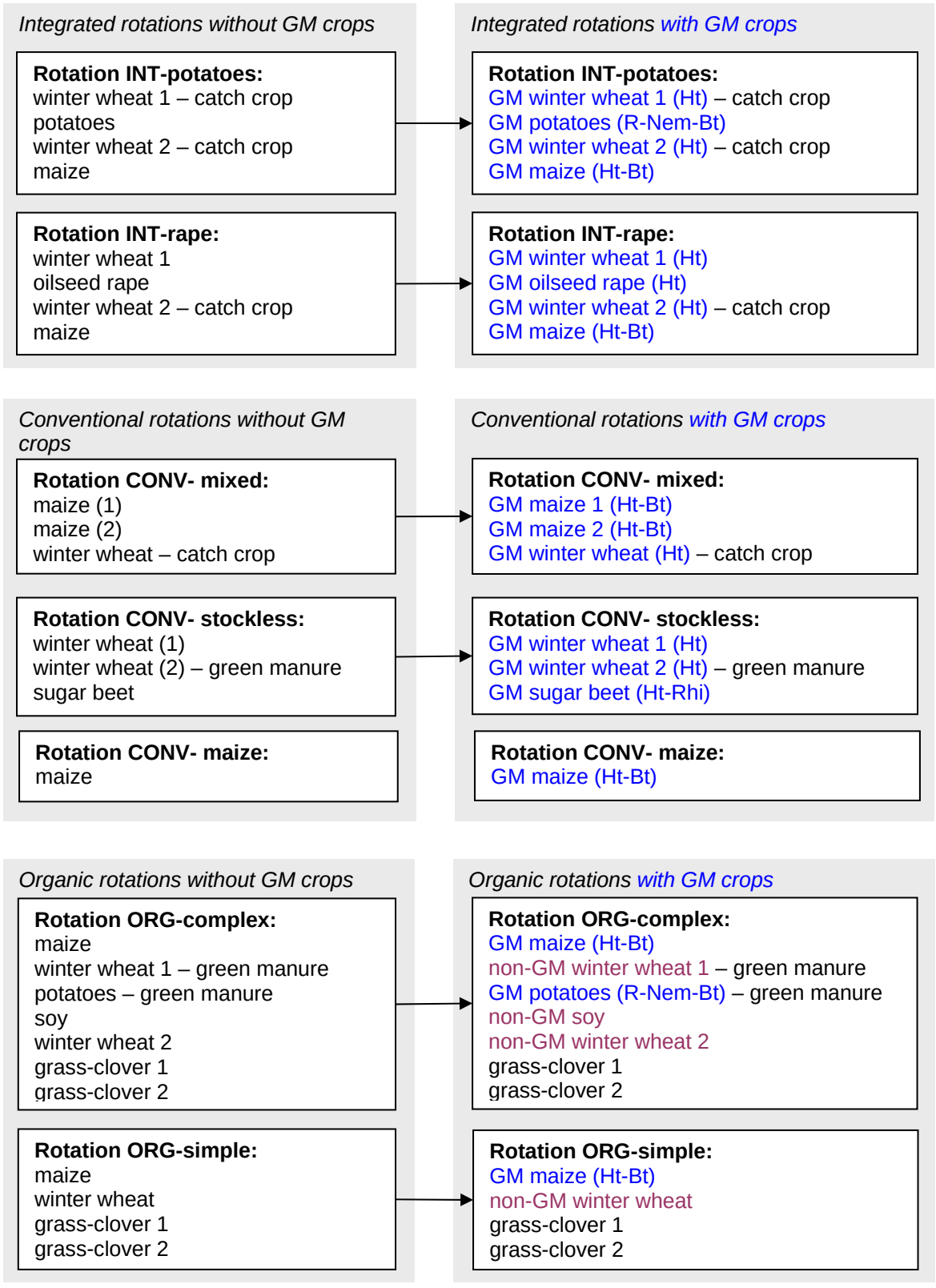
4 Detailed description of the crop rotations

An overview of the crop rotations is given in figure 1. All rotations are described in detail in chapters 4.1 to 4.7 below.

Maize monocultures are almost unknown in Switzerland at present. With non-GM maize, they would be difficult to implement because of problems with the European corn borer and the corn rootworm. With Bt-maize, however, these problems could be overcome. This rotation was therefore included in the scenarios.

Note: for some rotations, the experts identified potential problems already when they were designed. For example, some rotations do not fulfil the ÖLN production rules, and in some rotations, problems with *Fusarium* are expected. Also, GM rape was considered unlikely to be registered in Switzerland, because of its likelihood for outcrossing. Nevertheless, it was decided to keep these rotations in the scenarios, and consider such problems in the impact assessments.

Figure 1: Overview of crop rotations. Black font = conventional crops; Blue = GM crops (with traits indicated; traits: Ht = herbicide tolerant; Bt = insect resistant through Bt genes; R = R-genes for resistance to *Phytophthora infestans*; Nem = nematode resistant; Rhi = resistance to rhizomania); purple = although GM varieties are available for these crops, they are not included in the GM rotations (the only trait of the ideotype soy & wheat GM crops is herbicide tolerance; this trait is useless in organic farming, where herbicides are not allowed).



4.1 Rotation INT-potatoes

Table 4: Detailed description of the rotation INT-potatoes. For details on fertilization and yield see tables 1 & 2. For mineral fertilizers, amounts are given in kg/ha for each nutrient. The scenario without GMO is based on minimum tillage; the scenario with GM crops on direct drilling. Black = identical treatments for both scenarios; green = differing treatments in the two scenarios.

Crop / Date	INT-potatoes without GMO	INT-potatoes with GMO
winter wheat 1		
Mid Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)
End of July	Grain harvest (60dt), straw harvest, mulching of stubbles	Grain harvest (60dt), straw harvest, mulching of stubbles
catch crop		
Mid Aug.	Harrowing, sowing, rolling	Harrowing, sowing, rolling
Mid Aug	NPKMg-fertilization (30 / 25 / 90 / 10)	NPKMg-fertilization (30 / 25 / 90 / 10)
Mid March	Harvest of green manure (25 dt DM)	Harvest of green manure (25 dt DM)
potatoes		
Early April	NPK-fertilization (70 / 20 / 100)	NPK-fertilization (70 / 20 / 100)
Mid April	Manure (25 t), plow, harrow	Manure (25 t), plow, harrow
Mid April	Plough, harrow, planting	Plough, harrow, planting
Early May	Herbicide (e.g. Condoral [metribuzine])	Herbicide (e.g. Condoral [metribuzine])
Mid May	Hoeing, harrowing, ridging	Hoeing, harrowing, ridging
End of May	Fungicide with contact action (e.g. Ditha-ne Neotec [mancozeb]) (control of late blight)	Fungicide with contact action (e.g. Ditha-ne Neotec [mancozeb]) (control of *Alternaria* & resistance management)
Early June	Hoeing, ridging	Hoeing, ridging
Early June	Systemic Fungicide (e.g. Consento [fen-amidone & propamocarb-hydrochloride]) (control of late blight)	No treatment
Early - Mid June	Systemic Fungicide (e.g. Consento [fen-amidone & propamocarb-hydrochloride]) (control of late blight)	No treatment
Mid June	treatment against potato beetles (Nomolt [tefluibenzurone]) every 3rd year[4]	No treatment
Mid June	Systemic Fungicide (e.g. Consento [fen-amidone & propamocarb-hydrochloride]) (control of late blight)	Systemic Fungicide (e.g. Consento [fen-amidone & propamocarb-hydrochloride]) (control of *Alternaria* & resistance management)
End of June	Partially systemic Fungicide (e.g. Acro-bat MZ WG [dimethomorph & manco-zeb]) (control of late blight)	No treatment

[4] Charles & Favre, ACW & Agridea, unpublished

Crop / Date	INT-potatoes without GMO	INT-potatoes with GMO
Early July	Partially systemic Fungicide (e.g. Acrobat MZ WG [dimethomorph & mancozeb]) (control of late blight)	Partially systemic Fungicide (e.g. Acrobat MZ WG [dimethomorph & mancozeb]) (control of *Alternaria* & resistance management)
Mid July	Fungicide with contact action (e.g. Dithane Neotec [mancozeb]) (control of late blight)	No treatment
End of July	Fungicide with contact action (e.g. Dithane Neotec [mancozeb]) (control of late blight)	No treatment
Early Aug.	Chemical haulm destruction (e.g. Spotlight [carfentrazone-ethyl])	Chemical haulm destruction (e.g. Spotlight [carfentrazone-ethyl])
Mid Aug.	Harvest (yield 450 dt, of which 80% is marketable)	Harvest (yield 450 dt, of which 80% is marketable)
winter wheat 2		
Mid Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexapac-ethyl])	Growth regulator (e.g. Moddus [trinexapac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazole]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazole]) against *Fusarium* (important in this rotation!)
End of July	Grain harvest (60dt), straw harvest, mulching of stubbles	Grain harvest (60dt), straw harvest, mulching of stubbles
catch crop		
Early Aug.	Harrow	Harrow
Mid Aug.	Harrowing, sowing, rolling	Harrowing, sowing, rolling
Mid Aug	NPKMg-fertilization (30 / 25 / 90 / 10)	NPKMg-fertilization (30 / 25 / 90 / 10)
Mid March	Harvest of green manure (25 dt DM)	Harvest of green manure (25 dt DM)
maize		
Mid April	Manure (30 t)	Manure (30 t)
Mid May	Herbicide (glufosinate)	Herbicide (glufosinate)
End of May	Cultivating, harrowing, sowing	Direct drilling
Mid June	Post-emergence herbicides (e.g. Callisto [mesotrione], Basagran [bentazone])	Glufosinate
Mid June	Slurry (20 m^3)	Slurry (20 m^3)
Early July	*Trichogramma* 1 (in the future perhaps more than 1 treatment)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (20 m^3)	Slurry (20 m^3)
End of Sept.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer)	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer)

4.2 Rotation INT-rape

Table 5: Detailed description of the rotation INT-rape. For further details see table 4.

Crop / Date	INT-rape without GMO	INT-rape with GMO
winter wheat 1		
Mid Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient -fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)
End of July	Grain harvest (60dt), straw harvest, mulching of stubbles	Grain harvest (60dt), straw harvest, mulching of stubbles
rape		
Mid Sept	PKMg-fertilization (65 / 110 / 15)	PKMg-fertilization (65 / 110 / 15)
Mid Sept	Harrowing, sowing	Direct drilling
Early Sept	Pre-emergence herbicide (e.g. Butisan [metazachlor])	Glufosinate (post-emergence), when weeds reach damage threshold. If need-ed, 2nd treatment in spring.
Mid Sept	Molluscicide (e.g. Metarex [metaldehy-de])	Molluscicide (e.g. Metarex [metaldehy-de])
Early March	N-fertilization (80)	N-fertilization (80)
End of March	Insecticide (e.g. Karate [lambda-cyhalo-thrine])	Insecticide (e.g. Karate [lambda-cyhalo-thrine])
Mid April	N-fertilization (60)	N-fertilization (60)
End of April	Insecticide (e.g. Karate [lambda-cyhalo-thrine]) & fungicide (every 3rd year; e.g. Tenor [carbendazim & difenoconazole])	Insecticide (e.g. Karate [lambda-cyhalo-thrine]) & fungicide (every 3rd year; e.g. Tenor [carbendazim & difenoconazole])
Early July	Harvest (grain yield 35 dt)	Harvest (grain yield 35 dt)
Mid Aug	Mulching of stubbles	Mulching of stubbles
winter wheat 2		
Mid Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)

Crop / Date	INT-rape without GMO	INT-rape with GMO
End of July	Grain harvest (60dt), straw harvest, mulching of stubbles	Grain harvest (60dt), straw harvest, mulching of stubbles
catch crop		
Early Aug.	Harrow	Harrow
Mid Aug.	Harrowing, sowing, rolling	Harrowing, sowing, rolling
Mid Aug	NPKMg-fertilization (30 / 25 / 90 / 10)	NPKMg-fertilization (30 / 25 / 90 / 10)
Mid March	Harvest of green manure (25 dt DM)	Harvest of green manure (25 dt DM)
maize		
Mid April	Manure (30 t)	Manure (30 t)
Mid May	Herbicide (glufosinate)	Herbicide (glufosinate)
End of May	Cultivating, harrowing, sowing	Direct drilling
Mid June	Post-emergence herbicides (e.g. Callisto [mesotrione], Basagran [bentazone])	Glufosinate
Mid June	Slurry (20 m^3)	Slurry (20 m^3)
Early July	*Trichogramma* 1 (in the future perhaps more than 1 treatment)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (20 m^3)	Slurry (20 m^3)
End of Sept.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer)	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer)

4.3 Rotation CONV-mixed

Table 6: Detailed description of the rotation CONV-mixed (for mixed farms). For further details see table 4.

Crop / Date	CONV-mixed without GMO	CONV-mixed with GMO
maize 1		
Mid April	Manure (30 t)	Manure (30 t)
End of April	Herbicide (glyphosate)	Herbicide (glyphosate)
End of May	Cultivating, harrow, sowing	Direct drilling
Mid June	Post-emergence herbicides (e.g. Callisto [mesotrione], Basagran [bentazone])	Glufosinate
Mid June	Slurry (20 m^3)	Slurry (20 m^3)
Early July	*Trichogramma* 1 (in the future perhaps more than 1 treatment)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (20 m^3)	Slurry (20 m^3)
Mid Oct.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer)	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer)
maize 2		
Mid April	Manure (30 t)	Manure (30 t)
End of April	Herbicide (glyphosate)	Herbicide (glyphosate)
End of May	Cultivating, harrow, sowing	Direct drilling
Mid June	Post-emergence herbicides (e.g. Callisto [mesotrione], Basagran [bentazone])	Glufosinate
Mid June	Slurry (20 m^3)	Slurry (20 m^3)
Early July	*Trichogramma* 1 (in the future perhaps more than 1 treatment)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (20 m^3)	Slurry (20 m^3)
Mid Oct.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer). Problems with *Diabrotica*: lower yield. Problems with *Fusarium* expected.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer). No problems with *Diabrotica*. Problems with *Fusarium* expected.

Crop / Date	CONV-mixed without GMO	CONV-mixed with GMO
winter wheat		
End of Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)
End of July	Grain harvest (60dt), straw harvest (70 dt), mulching of stubbles	Grain harvest (60dt), straw harvest (70 dt), mulching of stubbles
catch crop		
Mid Aug.	Harrowing, sowing, rolling	Harrowing, sowing, rolling
Mid Aug	NPKMg-fertilization (30 / 25 / 90 / 10)	NPKMg-fertilization (30 / 25 / 90 / 10)
Mid March	Harvest of green manure (25 dt DM)	Harvest of green manure (25 dt DM)

4.4 Rotation CONV-stockless

Table 7: Detailed description of the rotation CONV-stockless (for stockless farms). For further details see table 4.

Crop / Date	CONV-stockless without GMO	CONV-stockless with GMO
winter wheat 1		
Mid Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)
End of July	Grain harvest (60dt), straw harvest, mulching of stubbles	Grain harvest (60dt), straw harvest, mulching of stubbles
winter wheat 2		
Mid Oct.	PKMg-fertilization (60 / 100 / 15)	PKMg-fertilization (60 / 100 / 15)
End of Oct.	Rotary harrow, sowing	Direct drilling
Early March	Herbicides against monocots & dicots (e.g. Husar [iodosulfuron-methyl sodium] + Rasantan [amidosulfuron / bromoxynil / diflufenican])	Herbicide (glyphosate)

Crop / Date	CONV-stockless without GMO	CONV-stockless with GMO
Early March	N-fertilization (40)	N-fertilization (40)
End of March	No micronutrient fertilization	Micronutrient fertilization
Mid April	N-fertilization (60)	N-fertilization (60)
Mid April	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])	Growth regulator (e.g. Moddus [trinexa-pac-ethyl])
Mid May	N-fertilization (40)	N-fertilization (40)
Mid May	Fungicide (e.g. chlorothalonil) against foliar diseases	Fungicide (e.g. chlorothalonil) against foliar diseases
Mid June	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)	Fungicide (e.g. Proline [prothioconazo-le]) against *Fusarium* (important in this rotation!)
End of July	Grain harvest (60dt), straw harvest, mulching of stubbles	Grain harvest (60dt), straw harvest, mulching of stubbles
green manure		
Early Aug.	Harrow	Harrow
Mid Aug.	Sowing (crucifers)	Sowing (crucifers)
Early March	Mulching	Mulching
sugar beet		
Early March	PKMg-fertilization (85 / 465 / 70)	PKMg-fertilization (85 / 465 / 70)
Early March	Herbicide (glyphosate)	Herbicide (glyphosate)
End of March	Cultivating, harrowing, sowing	Direct drilling (under good soil condi-tions), glufosinate (full dose)
Early April	N-fertilization (40)	N-fertilization (40)
Mid April	Post-emergence herbicide 1 (half dose) (e.g. Betanal [desmedipham, ethofume-sate, phenmedipham])	No treatment
End of April	Molluscicide (e.g. Metarex [metaldehy-de])	Molluscicide (e.g. Metarex [metaldehy-de])
Early May	N-fertilization (60)	N-fertilization (60)
Early May	Post-emergence herbicide 2 (half dose) (e.g. Betanal [desmedipham, ethofume-sate, phenmedipham])	Glufosinate (full dose)
Early June	Post-emergence herbicide 3 (half dose) (e.g. Betanal [desmedipham, ethofume-sate, phenmedipham])	No treatment
Mid June	Insecticide against aphids (e.g. Pirimor [pirimicarb])	Insecticide against aphids (e.g. Pirimor [pirimicarb])
Early August	Fungicide (e.g. Avenir [fenpropimorph, difenoconazole])	Fungicide (e.g. Avenir [fenpropimorph, difenoconazole])
Mid Oct.	Harvest (yield 75 t)	Harvest (yield 75 t)

4.5 Rotation CONV-maize

Table 8: Detailed description of the rotation CONV-stockless (for stockless farms). For further details see table 4.

Crop / Date	CONV-maize without GMO	CONV-maize with GMO
maize		
Mid April	Manure (30 t)	Manure (30 t)
End of April	Herbicide (glyphosate)	Herbicide (glyphosate)
End of May	Cultivating, harrow, sowing	Direct drilling
Mid June	Post-emergence herbicides (e.g. Callisto [mesotrione], Basagran [bentazone])	glyphosate (year 1); glufosinate (year 2)
Mid June	Slurry (20 m^3)	Slurry (20 m^3)
Early July	*Trichogramma* 1 (in the future perhaps more than 1 treatment)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (20 m^3)	Slurry (20 m^3)
Mid Oct.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer) Problems with *Fusarium* expected.	Harvest maize for sileage (yield 175 dt DM), mulching of stubbles (against *Fusarium* & corn borer) Problems with *Fusarium* expected.

4.6 Rotation ORG-complex

Table 9: Detailed description of the rotation ORG-complex. For further details see table 4.

Crop / Date	ORG-complex without GVO	ORG-complex with GVO
maize		
Mid April	Manure (35 t)	Manure (35 t)
Early May	Plowing, rolling	Plowing, rolling
Mid May	Slurry (25 m^3)	Slurry (25 m^3)
End of May	Harrowing, sowing (re-sowing in case of crow damage)	Harrowing, sowing (re-sowing in case of crow damage)
End of June	Harrow	Harrow
Early July	*Trichogramma* 1	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (25 m^3)	Slurry (25 m^3)
Mid July	*Trichogramma* 2	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
August	*(Trichogramma* 3 & 4, in case of 2nd generation of corn borer)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
End of Sept.	Harvest maize for sileage (yield 160 dt)	Harvest maize for sileage (yield 160 dt)
Early Oct.	Mulching of stubbles (against *Fusarium* & corn borer)	Mulching of stubbles (against *Fusarium* & corn borer)
winter wheat 1		
Early Oct.	Plowing	Plowing
Mid Oct.	Harrowing	Harrowing
End of Oct.	Sowing	Sowing
Early March	Slurry (30 m^3)	Slurry (30 m^3)
Early April	Slurry (20 m^3)	Slurry (20 m^3)
Mid April	Harrowing	Harrowing
End of July	Grain harvest (50 dt), straw harvest, mulching of stubbles	Grain harvest (50 dt), straw harvest, mulching of stubbles
Early Aug.	Harrow	Harrow
green manure		
Mid August	Slurry (30 m^3)	Slurry (30 m^3)

Crop / Date	ORG-complex without GVO	ORG-complex with GVO
Mid August	Harrowing, sowing (legumes), rolling	Harrowing, sowing (legumes), rolling
Mid March	Mulching, plowing	Mulching, plowing
potatoes		
Early April	Slurry (30 m^3)	Slurry (30 m^3)
Early April	Potassium sulfate (100 kg)	Potassium sulfate (100 kg)
Early April	Harrow	Harrow
Mid April	Rotary harrow, planting	Rotary harrow, planting
Mid April	Organic N fertilizer (30 kg N)	Organic N fertilizer (30 kg N)
Early May	Hoeing, harrowing, ridging	Hoeing, harrowing, ridging
Mid May	Slurry (30 m^3)	Slurry (30 m^3)
Mid May	Hoeing, harrowing, ridging	Hoeing, harrowing, ridging
End of May	Slurry (15 m^3)	Slurry (15 m^3)
End of May	Fungicide (e.g. Cuprofix [copper oxy-chloride])	No treatment
Early June	Hoeing, ridging	Hoeing, ridging
Early June	Fungicide (e.g. Cuprofix [copper oxy-chloride]) mainly against late blight	Fungicide (e.g. Cuprofix [copper oxy-chloride]) against *Alternaria* and for resistence management.
Mid June	Treatment against potato beetle (Novodor [*Bacillus thuringiensis* var. *tenebrionis*])	No treatment
Mid June	Fungicide (e.g. Cuprofix [copper oxy-chloride]) mainly against late blight	Fungicide (e.g. Cuprofix [copper oxy-chloride]) against *Alternaria* and for resistence management.
Mid June	Treatment against potato beetle (Novodor [*Bacillus thuringiensis* var. *tenebrionis*])	No treatment
June	Irrigation 2x 20 mm	Irrigation 2x 20 mm
End of June	Fungicide (e.g. Cuprofix [copper oxy-chloride]) mainly against late blight	Fungicide (e.g. Cuprofix [copper oxy-chloride]) against *Alternaria* and for resistence management.
Early July	Fungicide (e.g. Cuprofix [copper oxy-chloride])	No treatment
Mid July	Fungicide (e.g. Cuprofix [copper oxy-chloride])	No treatment
Early Aug.	Mechanical haulm destruction (flailing)	Mechanical haulm destruction (flailing)
Mid Aug.	Harvest (yield 250 dt), of which 70 % marketable	Harvest (yield 275 dt), of which 80 % marketable
green manure		
End of Aug.	Harrowing, sowing (legumes), rolling	Harrowing, sowing (legumes), rolling
Early May	Mulching, plowing	Mulching, plowing
soy beans		
Early May	Rotary harrow, sowing (seed inoculated with rhizobia[5]).	Rotary harrow, sowing (seed inoculated with rhizobia[5]).
Early June	Harrowing, hoeing	Harrowing, hoeing
Mid June	Hoeing[6]	Hoeing[6]
End of Oct.	Harvest (yield 21 dt), mulching of straw	Harvest (yield 21 dt), mulching of straw
winter wheat 2		
End of Oct.	Manure (25 t), harrowing	Manure (25 t), harrowing
Early Oct.	Plowing	Plowing
Mid Oct.	Harrowing	Harrowing
End of Oct.	Sowing	Sowing
Early March	Slurry (30 m^3)	Slurry (30 m^3)

[5] More efficient rhizobia than today are expected to be available within the next decade

[6] Note: Currently, organic soy is hand-weeded (40 h/ha). For the scenarios, it is assumed that hand-weeding is replaced by the harrow.

Crop / Date	ORG-complex without GVO	ORG-complex with GVO
Early April	Slurry (20 m^3)	Slurry (20 m^3)
Mid April	Harrowing	Harrowing
End of July	Grain harvest (50 dt), straw harvest, mulching of stubbles	Grain harvest (50 dt), straw harvest, mulching of stubbles
Early Aug.	Harrowing	Harrowing
grass-clover 1		
Early Aug.	Manure (10 t), harrow	Manure (10 t), harrow
Early Aug.	Rotary harrow, sowing, rolling	Rotary harrow, sowing, rolling
Early March	Slurry (30 m^3)	Slurry (30 m^3)
Early May	Cut 1	Cut 1
Mid May	Slurry (20 m^3)	Slurry (20 m^3)
End of May	Cut 2	Cut 2
End of July	Cut 3	Cut 3
Mid Sept.	Cut 4	Cut 4
End of Oct.	Cut 5 (total annual harvest 85 dt DM)	Cut 5 (total annual harvest 85 dt DM)
grass-clover 2		
Early March	Slurry (30 m^3)	Slurry (30 m^3)
Early May	Cut 1	Cut 1
Mid May	Slurry (20 m^3)	Slurry (20 m^3)
End of May	Cut 2	Cut 2
End of July	Cut 3	Cut 3
Mid Sept.	Cut 4	Cut 4
End of Oct.	Cut 5 (total annual harvest 100 dt DM)	Cut 5 (total annual harvest 100 dt DM)

4.7 Rotation ORG-simple

Table 10: Detailed description of the rotation ORG-simple. For further details see table 4.

Crop / Date	ORG-simple without GVO	ORG-simple with GVO
maize		
Mid April	Manure (25 t)	Manure (25 t)
Early May	Plowing (10cm =reduced tillage), rolling	Plowing (10cm =reduced tillage), rolling
Mid May	Slurry (30 m^3)	Slurry (30 m^3)
End of May	harrowing, sowing (re-sowing in case of crow damage)	harrowing, sowing (re-sowing in case of crow damage)
End of June	Harrow	Harrow
Early July	*Trichogramma* 1	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
Early July	Slurry (30 m^3)	Slurry (30 m^3)
Mid July	*Trichogramma* 2	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
August	*(Trichogramma* 3 & 4, in case of 2nd generation of corn borer)	No treatment on 80 % of the surface; treatment on 20 % (resistance management)
End of Sept.	Harvest maize for sileage (yield 160 dt)	Harvest maize for sileage (yield 160 dt)
Early Oct.	Mulching of stubbles (against *Fusarium* & corn borer)	Mulching of stubbles (against *Fusarium* & corn borer)
winter wheat		
Early Oct.	Plowing (10cm =red. tillage), harrowing	Plowing (10cm =red. tillage), harrowing
Mid Oct.	Harrowing	Harrowing
End of Oct.	Sowing	Sowing
Early March	Slurry (20 m^3)	Slurry (20 m^3)
Early April	Slurry (20 m^3)	Slurry (20 m^3)
Mid April	Harrowing	Harrowing
End of July	Grain harvest (50 dt), straw harvest, mulching of stubbles	Grain harvest (50 dt), straw harvest, mulching of stubbles

Crop / Date	ORG-simple without GVO	ORG-simple with GVO
Early Aug.	Harrowing	Harrowing
grass-clover 1		
Mid August	Manure (10 t)	Manure (10 t)
Mid Aug.	Rotary harrow, sowing, rolling	Rotary harrow, sowing, rolling
Early March	Slurry (30 m^3)	Slurry (30 m^3)
Early May	Cut 1	Cut 1
Mid May	Slurry (20 m^3)	Slurry (20 m^3)
End of May	Cut 2	Cut 2
End of July	Cut 3	Cut 3
Mid Sept.	Cut 4	Cut 4
End of Oct.	Cut 5 (total annual harvest 100 dt DM)	Cut 5 (total annual harvest 100 dt DM)
grass-clover 2		
Early March	Slurry (30 m^3)	Slurry (30 m^3)
Early May	Cut 1	Cut 1
Mid May	Slurry (20 m^3)	Slurry (20 m^3)
End of May	Cut 2	Cut 2
End of July	Cut 3	Cut 3
Mid Sept.	Cut 4	Cut 4
End of Oct.	Cut 5 (total annual harvest 100 dt DM)	Cut 5 (total annual harvest 100 dt DM)

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