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Analysis of mechanization of intercropping systems in Western Europe

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Preface

The present report is the final stage of my master in Biosystems engineering. The topic selected for this purpose was intended to be useful as for analyzing the technological component of the arable system in the context of highly mechanized sector, such as the European one. The value of this dissertation subscribes in my learning process of how to proceed with the Biosystems design discipline, which has been a challenge in many aspects for me. I would like to thank to my supervisors, to have the patience and give me the necessary guidance to go through a complex task that led me to learn the key components of the engineering process in a biosystem that integrates the biological, technological, and human component.

Jose A. Mora

Summary

An analysis of the mechanization of strip intercropping was elaborated, in terms of the innovation needed to implement. The approach taken was to follow a structured design process through which the needs reflected by a list of requirements were to be assessed against a conceptualization of an intercropping system. During the process, a functional analysis was done in order to find systematically the current solutions for a generic arable cropping system that not specifies the species. A valid demarcation of intercropping systems in order to analyze the technological aspect of mechanization was done in the present report. Only two features were selected to depict the spatial and temporal organization aspect of intercrops namely, strip width dimension and the time synchronization pattern. In order to conceptualize a biological system that is not yet fully optimized from the agronomic perspective, as the intercropping systems in the context of West Europe, a choice was made to demarcate the analysis in the light of limited time available (Strip intercropping with a width of 3 meter). Furthermore, the choice was meant as a first step to systematically find the issues to be solved going from a state of transition in innovation towards a fully new intercropping system design, that may chase agro ecological intensification goals, including those belonging to the conservation of natural resources.

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1 Introduction

1.1 Current situation

1.1.1 Arable crop sector in Western Europe

The arable crop sector in Western Europe, as well as in the developed world can be roughly characterized as of highly in input use such as fertilizers and pesticides, as well as highly mechanized. (Licker et al. 2010) recognized that the yield gap between the obtained yields of crop systems as compared to its potential in Western Europe, is among the lowest in the global scale, mainly due to the agricultural practices. That portrait an intensive agricultural system, which has been successful in getting attainable crop yields. On the other hand, such intensive cropping systems have had adverse impacts on water quality, soil quality, and biodiversity of natural ecosystems (Licker et al. 2010).

1.1.2 Intercropping systems as an alternative

Intercrops are reported to be more efficient in natural resources utilization and to have a yield advantage compared to sole cropping systems. It is usually measured as land equivalent ratio, whenever its value is major larger than 1 represents an advantage versus its corresponding sole crops because it needs less land to produce the same amount, in average the LER (Land Equivanlent Ratio) values among intercropping experimental data is 1.22 +/- 0.02 (Yang Yu et al. 2015). In addition, several advantages have been documented such as reducing economic impact of crop failure, conserving soil, improving soil fertility, improving forage quality; lodging resistance to prone crops, reducing pest and disease incidence, and promoting biodiversity (Lithourgidis et al. 2011).

Interest in intercrops was renewed since the last 20 years at researcher level in the developed countries in the light of extra marketing benefits considering intercrops for the production of homemade forages. Growth complementarities of intercrops that induce reduction of fertilizer and pesticide use, criticism to monoculture cropping systems, and the advent of technology suitable to drilling and harvesting intercrops have been reasons behind this renewed interest (Anil et al. 1998).

However, Vandermeer (1989), although with skepticism mentioned the statement among scientists, that the viability of intercrops within developed countries was believed to be either impossible or inefficient as compared to sole crops, because of mechanization issues. Such statement Vandermeer did not considered as valid because of its lack of formal evidence. More recent, (de Veer, J. et al. 2014) based on interviews with agricultural equipment manufacturers in the Netherlands argue that mechanizing strip intercropping systems is already possible with the existing technology, however no studies had approached how the mechanical solutions would look like and what sort of limitations are to be lifted by designing new equipment. Lithourgidis et al. (2011) claim that the adverse attitude towards practices of diversification represented in intercropping systems are explained by sociological and financial impediments, rather than technological ones.

Intercrops might represent an alternative to the current arable farming sector in Europe in order to achieve several natural resource preservation goals. However, what remains as an obstacle to implement it, is the lack of specific machinery designed to operate a variety of intercrops within a socioeconomic context such as the western European one, where the potential benefits for intercropping are known to a limited extent.

1.2 Desired situation

Western European farmers have adopted intercropping systems as a strategy to achieve natural resource preservation goals. The machinery system that performs its field operations has been designed and is used accordingly. Sustainability goals are achieved by an efficient production of safe, high quality arable crop products, while protecting the natural environment and the social and economic conditions of farmers.

1.3 Goal of the study

In order to contribute to the realization of the desired situation, the current study was meant to identify the necessary innovations with regard to its machinery system required to implement intercropping systems in the context of Western Europe.

1.4 Research questions

- How can we derive a valid demarcation to intercropping systems in order to analyze the technological aspects of mechanization in the context of Western Europe?
- What goals and requirements are needed in order to realize a sustainable intercropping system in relation to its machinery component?
- What functionalities are playing a role in future machinery for intercrops in the light of sustainability goals?
- What are the shortcomings of the current machinery principles when they applied to intercrops that can be adapted or redesigned?

1.5 Approach and demarcation

A structured design approach was taken, from which an analysis and overview of functions and principles, respectively and regarding the machinery system was done. The approach was to identify in hierarchal manner the functions at work for realizing a generic arable crop system, and to clarify whether the same functions apply both for the conventional arable crop systems and to intercropping systems. Both regarded as part of the generic arable crop system.

However, a new design of machinery for intercrops was not pursued.
In this study, literature has been used to find relevant information regarding crop machinery principles; in addition, students with farming background were interviewed as a method to answer the research questions.
No experiments were carried out, or calculation models whatsoever were used.
No concrete examples of intercropping systems actually cultivated in Europe will be used as the desired situation. This was meant intentionally to generalize the results to a broader range of intercropping systems that are not currently adopted but might be in the future.

2 Methodology

2.1 Structured design

The approach taken to answer the research questions consisted in using the structured design methodology as the theoretical framework. However, a complete new design was not pursued. Since the focus of the study was not put on a specific combination of annual crops but rather on a generic intercropping system, elaborating a new design might have turned too uncertain to evaluate. In addition, although in general the purpose of a design process is to render a new product or machine, actually most designing is a variation of existing products or machines, which reflect that usually customers prefer improvements rather than novelties (Cross 2008).

Figure 1 shows the overall process of the structured design as proposed by Van den Kroonenberg (2002). By splitting the process of design in a systematic way, the chances of overlooking essential items are reduced while increasing the chances of getting feasible designs.

Noteworthy, even if it seems a linear process it is actually is an iterative one, for instance, analyzing functions can reveal issues that were not considered in the first state of problem definition. Furthermore, it is through a diverging process and then through a converging process that the milestones of the design process are obtained namely: objective, function, and structure. These allow going from the abstract to the concrete and from the problem to a solution.

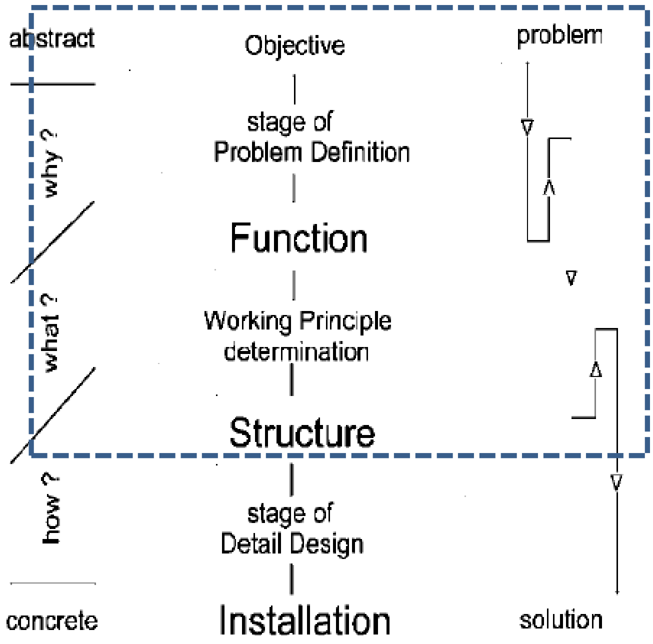


Figure 1: Methodical design process proposed by Van den Kroonenberg (2002). The dashed blue rectangle contains the steps that are included in the present study.

The present study was formulated by adapting the structured design process to a set of activities in the light of answering the research questions. Figure 2 schematizes the main activities and outcomes for the present report.

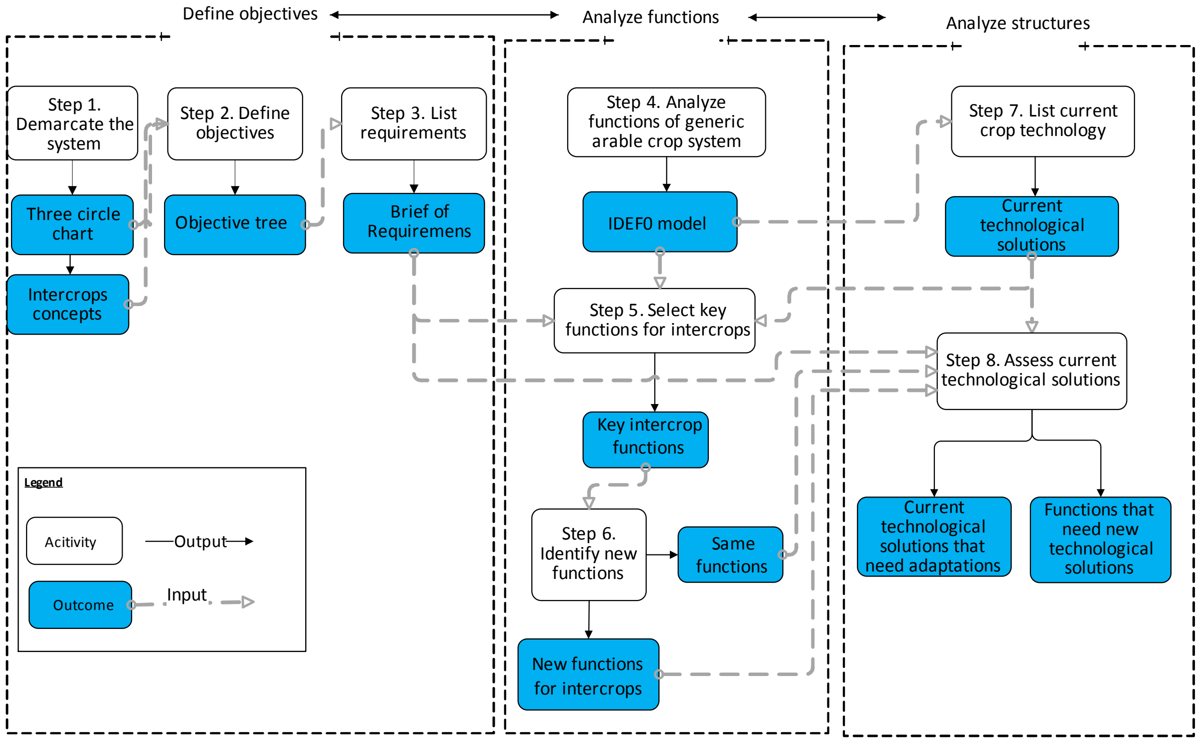


Figure 2: Activities and outcomes diagram of the present study. Numbers show the steps that are expanded through the methodology

In the following subsections 2.2, 2.3, 2.4 the activities and outcomes are explained.

2.2 Define objectives

2.2.1 Step 1: Demarcate the system

A System analysis approach was taken to define the target system to be studied in the light of the desired situation. The following subsections describe the methods used to determine the focus of the study (section 2.2.1.1), and to determine the criteria to define intercropping systems within the current study (section 2.2.1.2).

2.2.1.1 Three circle analysis

The method consisted in describing 'reality' according to the author's point of view, who identify relevant objects and subjects (e.g., agricultural inputs and machinery) and position them within nested circles that represent different levels of 'reality' (e.g. the universe, natural environment, farm, etc.). In that way, the boundaries of the system to be studied were established more precisely. Accounting the existence of subjects and objects outside the target system's boundaries was considered to have influence in it. A brief description was done in terms of the relations between the subject and object at different levels of reality in order to understand the context of the target system, and to delimitate the elements that would not take explicitly part of the analysis in the present report.

2.2.1.2 Intercropping system concept definition

What was the intercropping concept definition?

The concept definition was meant to describe as detailed as possible what comprises intercropping systems in terms of its leading features that could influence the mechanization process. The purpose was to define the concepts of intercropping systems that were under enquiry in this report. Furthermore, it was intended to find the characteristics that describe intercropping system's universe without referring to specific concrete cases, in an attempt to generalize the conclusions of the study afterwards to a broader range of systems, which are not yet implemented in the context of Western Europe.

How was done?

Using information published about intercropping systems around the world (cited in section 3.1), an intercropping system's concept definition was elaborated. The information extracted was about:

1. What is the focus of intercropping research in Europe and in the world?
2. What features defines in a generic way intercropping systems without referring to concrete cases
3. What concept/s was/were selected for analysis in the present report?

Why it was done?

The concept definition was necessary in order to analyze the mechanization prospective of the current technological solutions applied to that conception. Considering that the adoption of intercropping systems in Western Europe is limited to a small proportion of the total arable land, and the knowledge of plant scientist are still under development, the step of defining a concept rather than selecting a real case was justified at this stage of research and development of intercropping systems in Western Europe.

2.2.2 Step 2: Define objectives

The starting point of the structured design is the preliminary research of needs that will be satisfied by a 'new design', and determines largely the chances of success of it (Van den Kroonenberg 2002). The RIO (Reflective interactive design) approach of interactive innovation has set the analysis of needs of key actors as a pivotal point with the active participation of stakeholders (Bos et al. 2009).

Although the present study did not aim at a new particular design for mechanizing of a particular intercropping system, it was regarded as fundamental to define objectives. Those were the criteria to evaluate the current technology in order to determine its applicability to intercropping systems, and therefore defining adaptations or new technology, which are needed in the light of such objectives.

Such definition of objectives was done by identifying the actors (positioned in the step 1 demarcation of the system) and reflecting on their needs. 'Needs' are eventually the motivation to implement intercropping systems from which issues emerge that ought to be solved. Some literature was used to underpin the needs that are supposed to be satisfied by implementing intercropping systems.

An objectives tree was the method to acknowledge the needs and issues to be addressed in the desire situation, which were assumed to be experienced by actors identified firstly. The tree shows hierarchical relations between needs and its corresponding issues, thus, structuring the needs from higher level of generality to specific level (Cross 2008). Assumptions were made regarding the relevance of those needs, which means that no primary data were collected in order to define them and prioritize them, but an intuitive search for reasonable motivation of those needs was based on publications around the European agricultural sector.

2.2.3 Step 3: List requirements

The brief of requirements is the list of constraints, conditions, performance specifications that machinery system of generic intercrops has to comply in accordance with the pre-defined objectives in step 2. In the present report, the template from the Biosystems design course (Ooster and Vroegindeweij 2013) was used for setting up the brief of requirements. Scientific and technical publications were searched and used to underpin the requirements as on behalf of the stakeholders whose voice were not included explicitly, that is, to support claims that were considered as relevant to the author.

According to the structured design methodology (Van den Kroonenberg 2002), the level of generality in which the requirement is defined is an important consideration. The level of generality can be structured as technical installation, complex tool, tool, component, and part, as can be seen in the Figure 3. The design process starts from the higher level of generality and goes downwards.

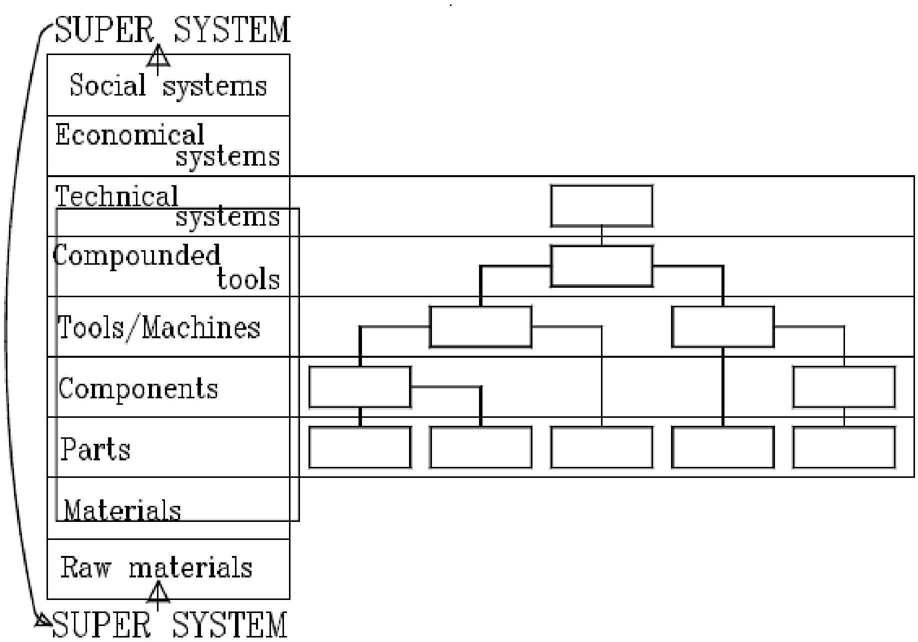


Figure 3: Hierarchal coherence in technical installations (Van den Kroonenberg 2002).

Starting from the actors identified in the tree circle chart, and then accounting for their needs in terms of the issues that need to be addressed, the requirements were proposed for the machinery system and its corresponding range of acceptable values in terms of an indicator based on available literature. The purpose of setting requirements was to establish quantitative limits of acceptability of the current technology principles as for being used in intercrops machinery system.

2.3 Analyze Functions

From the structured design approach, the function analysis represents an important step in order to define precisely the design problem (Van den Kroonenberg 2002). For the present study, function analysis also represented a necessary approach as to define in abstract terms the essential functionalities for mechanizing intercropping systems as prior step to determine if the current machinery principles can perform those functionalities and to know what shortcomings they have to be faced in the assessment step.

Two activities were performed, firstly decomposing a generic arable crop system into its functions using the IDEF0 methodology (step 4), and secondly selecting functions that are playing a role in order to meet the brief of requirements (step 5).

2.3.1 Step 4: Analyze functions of generic arable crop system

A functional model was elaborated to decompose the arable crop system into its functions in a systematic way. The aim was to generalize the current field operations (e.g. spreading fertilizers, spraying pesticides) on arable crops in terms of activities detached from specific real solutions (e.g. Apply nutrients, protect crops) using the IDEF0 (Integration definition language 0) function modelling language (Mayer 1992). Each activity is called herein after a function, which uses inputs in order to produce outputs, 'mechanisms' that provide its means, and 'controls' that establish conditions to a function in order to produce correctly its outputs (Figure 4) (Mayer 1992). Furthermore, the purpose of the analysis was to identify the relations between functions at work for realizing a generic arable crop system in west Europe, and to clarify whether the same functions apply both for the conventional arable crop system and to the intercropping systems.

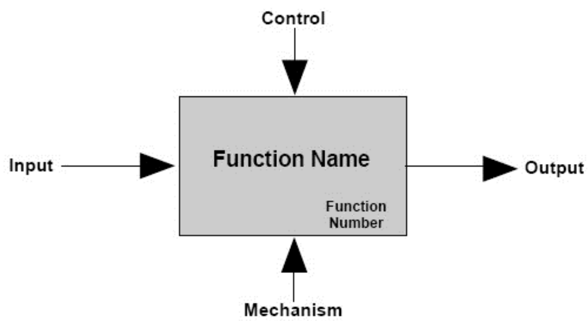


Figure 4: IDEF0 basic model component

According to the IDEF0 methodology, it is important to clarify the point of view of the analysis, for which in the present study is explained by defining the extent of meaning of inputs (left arrows), mechanism (bottom arrows), constraints (upper arrows) and outputs (right arrows), which are described as follows:

- **Inputs:** are the agricultural inputs in the form of mass, energy, or information, which are under human control. It includes natural resources, to transform them into food and feed products.
- **Mechanisms:** Technology, which entails the devices and tools that are used by machinery to perform functions (field operations represented as functions

in the diagram A0 section 3.2.1), are an essential mechanism from the focus of the study. Process & natural mechanisms, which entails the biological species interactions (e.g. plant, soil microorganisms, pest, and pest's enemies interrelations), make the production of food and feed possible in a particular way in the case of intercropping systems. The human labor, which mainly operate the working tools and devices, top soil profile as essential mechanism for an arable crop system that host the plant itself.

- **Controls:** The economics, environmental and consumer's constrains, which reflect the actor's needs behind them and determine how the production process is carried out every growing season in the light of those needs. For this particular study, they were embodied at different levels of generality as well as the brief of requirements (See section 3.1.3).
- **Outputs:** In biosystems the outputs are essentially mass, energy or information. The mass is translated mainly into food and feed products at field gate. Emissions and losses from the system were also identified as outputs, which are also controlled by the constraints and can be regarded as side-products in respect of how accurate are the mechanisms in transforming the inputs into the food and feed at the field gate. Additionally there are functions that produce information, for instance, certain devices that measure soil variables are determinant in order to perform other functions.

2.3.2 Step 5: Select key function for intercrops

This step was meant to identify the functions within the functional model elaborated in the step 4 that have a significant role in meeting the brief of requirements for intercropping machinery system elaborated in step 3. The function is what has to be done to achieve the desired results thus translating the objectives in technical terms (Van den Kroonenberg 2002).

Selection of key functions that play a role in meeting requirements was done by answering the three questions that are explained in Figure 5, those are a methodical way of finding the key functions.

Figure 5: Method to select the key functions for generic intercrops

The inputs to get the activity done were the brief of requirements, the current machinery principles (section 2.4) and the IDF0 model (Appendix 2). The criteria to answer the question Q1 was based on the perceptions of the people that was interviewed and the literature reviewed (see section 3.3.1). To answer the question Q2, a contradiction matrix was elaborated confronting the solution for each requirement and the expected consequence among other requirements, having as a source of information the people interviewed. Question 3 was answered by identifying the functions behind the solutions that need to be adapted or redesigned, using the IDEF0 model as the source.

2.3.3 Step 6: Identify new functions

The purpose of this step was to clarify whether the key functions identified in step 5 differ substantially to the functions that a generic crop system executes. The method used to identify new functions was a reflective exploration of the IDEF0 language used in the functional analysis. The outcome of it is to know whether the same functional structure could be applied to intercrops, and whether the difference would be expressed in terms of the constraints that shape the specific requirements to those functions, or be expressed in new functions.

2.4 Analyze solutions

2.4.1 Step 7: List current technological solutions

An overview of the current technological solutions for arable crop systems was made based on the IDFE0 model developed in step 4. Information available in technical literature was used as source of information ((Kitani 1999); (Srivastava 2006); (Demmel 2013); (Heege 2013b) (Gerhards 2013)**;** (Thiessen and Heege 2013); (van Lier, Pereira, and Steiner 1999); (Heege 2013a); (Chamen et al. 1994);("Agricultural Tractors — Rear-Mounted Power Take-off Types 1, 2 and 3 — Part 3: Main PTO Dimensions and Spline Dimensions, Location of PTO," n.d., `); ("Definitions and Classifications of Agricultural Field Equipment," n.d.); ("Terminology for Soil Engaging Components for Conservation Tillage Planters, Drills, and Seeders," n.d.))

One in-depth interview was used as the source of verification of how the engineering principles found in literature are present and used in the commercial nowadays-available equipment in the context of Western Europe. Various other multimedia elements available through Internet were used as a source of verification.

2.4.2 Step 8: Assessing current technological solutions

By contrasting current principles with the key functions that were identified for intercrops a question was formulated: are the current principles suitable for fulfilling intercrops functions and therefore meeting the brief of requirements? The following section shows the method to arrive to the answer.

2.4.2.1 Interviews with students of Biosystems Engineering program

What characteristics do they have?

To assess the current technological solutions regarding arable crop machinery, four students were selected based on their farming experience in the arable crop sector. The experience with current technology was one of the motivations to involve them into the assessment step. They were supposed to have employed and/or have acquired knowledge about the performance of current technological solutions in the arable farming systems in the context of the Netherlands, which was assumed representative of current state of innovation in Western Europe.

In addition, their scientific training was the second motivation to select them, because it was expected from them to give an objective assessment as possible detached from particular feelings to the current technology or to the legitimacy of sole cropping systems, feelings that can determine the judgement especially among farmers that reach maturity. Furthermore, they were expected to go beyond the preconceptions about what is realistic and what is not, as one of the attitudes advocated in the biosystems design course.

What was the script of the assessment session?

The script for the assessment session was the following: 1) Introduction to the purpose of the assessment session, 2) Introduction to the intercropping concept used in the present study 3) Presentation of the current machinery principles that are considered as technological solutions in the arable crop sector. 4) Presentation of the matrix that had to be filled-in, explaining the meaning of it, the scale used, and the way to interpret it. 5) Assessment of each requirement, recording the session and the underlying reasons for that

How was the assessment done?

The first part of the assessment was to score the variable requirements with 0-5 related to the degree of compliance of the current technological solutions to each requirement. '0' meant no compliance, meaning that current technological solutions cannot meet the requirement at its principle level. From one until five the scale represented how close the current technological solutions were from the target value of each variable requirement, whereas a five meant complete compliance and one meant to point the limit of acceptability within each requirement. The mean value, its standard deviation, and the coefficient of variation were calculated in order to see the variations among the answers. The assessment was recorded in audio, and the underpinning of each respondent's assessment was included in the table.

The second part of the assessment was to identify which sub-functions under the main functionalities addressed in the first part of the assessment were responsible for the gap between the target value and the actual score given by the respondents. The scale used was 1 till 5, meaning 5 no causal relationship and therefore no room for improvements, and 1 meaning that strong relation with the score given in the first part of the assessment and therefore a lot room for improvements in the technology that fulfill a certain function.

3 Results

3.1 Define objectives

3.1.1 Step 1: Demarcation of the system

3.1.1.1 Three circle analysis

Figure 6 depicts diagrammatically three major levels of reality: environment, farm, and strip intercropping system field. It contains the objects and subjects of interest that are explained by answering the following questions.

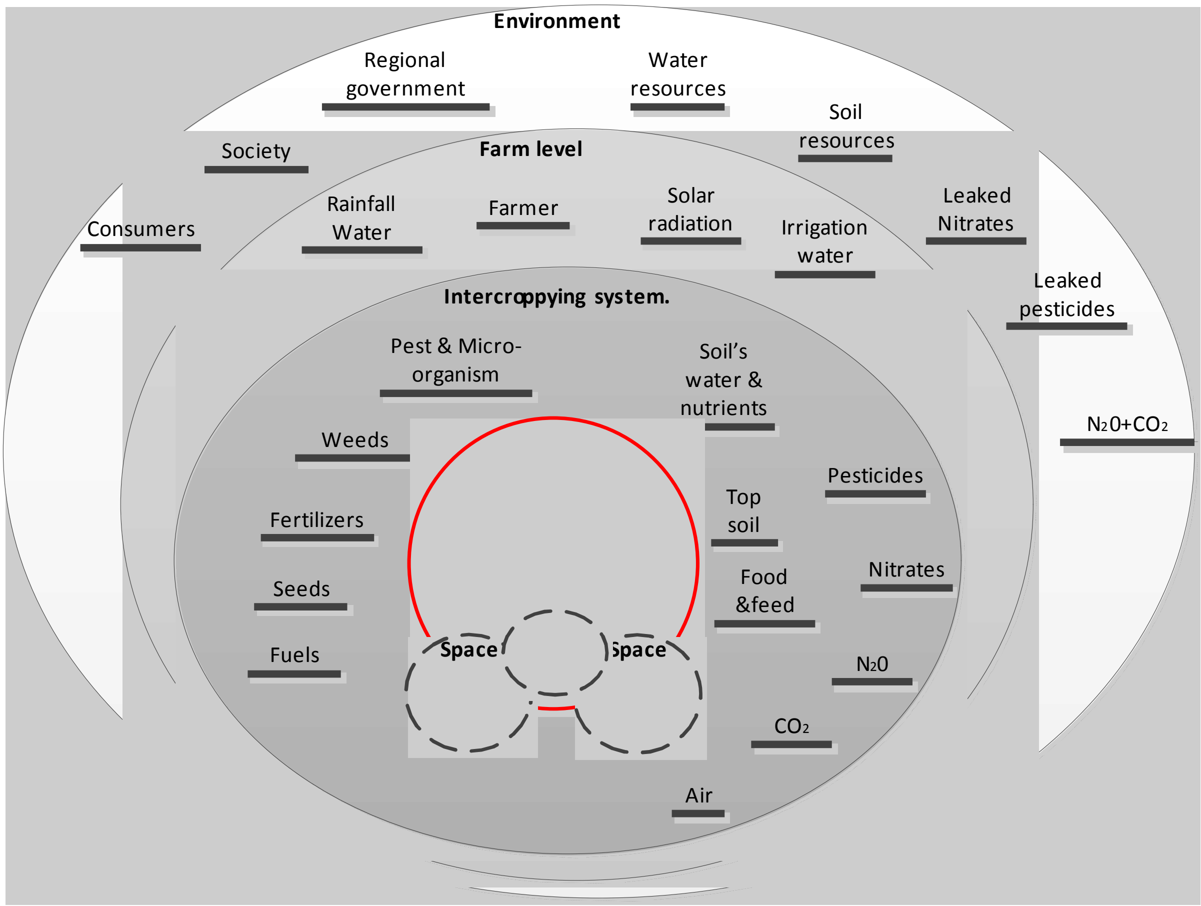


Figure 6: Three-circle analysis, demarcation of the machinery system within strip intercrop studied within the red circle.

What was identified at the environment level?

Within the environment, natural resources and its polluting agents were identified, in which the society has a stake on. Consumers, whose needs and expectations regarding the quality of agricultural products, may be considered and embedded into farm regulations that are issued by the government. These regulations in turn affect the production practices of every system at the farm level. Soil resources, which are fulfilling ecological functions such as carbon sequestration (Reference) are a concern from the environmental perspective because changes in soil properties led by agricultural practices can enact the liberation of greenhouse gases such as CO_2 and N_20 (reference). Water resources, which are polluted by the leakage of nutrients and pesticides from agricultural fields, are considered as important and society wants to regulate it through its government.

What objects were identified at the farm level?

Within the farm, the climate and the water resources gives information to the farmer, who manages according to this information and his/her needs the fields that compose it, among which strip intercropping field is of interest.

What were identified at the intercropping field level?

Within the intercropping system field, the plant species call for inputs including energy (in the form of fuels that move machinery), fertilizers of different nature (i.e. solid or liquid as for its physical state, artificial or organic as for its origin), and pesticides (i.e. preventive fungicides, herbicides, biological control agents and so on). The topsoil is the substrate for plants that stores water and nutrients, and its properties can be changed by the farmer's decisions. Plant species and each spatial configuration were identified as crucial for intercropping systems, which are to be designed according the needs of the stakeholders. The intercropping system fields embed the machinery system, which is an essential objectl to manipulate both inputs and the marketable outputs from the field.

What was the focus of the study within intercropping system?

The focus of the study was precisely the machinery system that comprises in the current situation a tractor, an operator and an implement in a broad overview. The machinery system operates, regardless of its precise spatial configuration, within two different areas either strips or rows with a border area between them. The plant species selection, which is out of the focus of the study, was intentionally done for two reasons: 1) there is a lack of knowledge of the preferable intercropping systems and its optimal configuration (besides the mixture of legumes and non-legumes species in mixed intercropping) in the context of west Europe. 2) The author's interest in explore only the technological aspect when it comes to mechanization as a priority according the time available for completing the study in a prospective alternative, which is not fully understood by the plant scientists.

3.1.1.2 Intercropping system's concepts definition

1) Intercrop classification and focus of past research:

(Vandermeer 1989) uses the conventional way to classify intercropping systems. He distinguished the following classes: Mixed intercropping, meaning no specific spatial arrangement of the species intercropped – usually a combination of legumes and non-legumes (Ghaley et al. 2005); (Kontturi et al. 2011); (Ledgard and Steele 1992). Relay intercropping, meaning that species intercropped are sown in different times for different reasons (Porter and Khalilian 1995) (Parajulee, Montandon, and Slosser 1997) (Zhang et al. 2007). Strip intercropping, where the intercropped species are placed in strips that let them interact while enacting the performing of activities independently, suggesting the embedding of conventional machinery or other means (e.g. manual tools) (References). However, that classification does not imply a mutual exclusion between the categories. Thus, it is not a systematic classification but rather a descriptive one in terms of how intercropping systems are usually designed, practiced, or studied by scientists.

Interestingly relay in not in fig 7, whereas row is, but not mentioned above

According to Yu et al. (In press), the research done in annual intercropping systems in Europe was by a majority of data records, among a global list of 50 top cited and 50 random publications cited between the years 2002 and 2013, focus on mixed intercropping of cereal and legume species, followed by row intercropping and then strip intercropping (See Figure 7 graph c). The purpose of mixed intercropping systems is generally to produce fodder for animal nutrition using the nitrogen biological fixation as an strategy to reduce the nitrogen inputs level (Anil, Park et al. 1998).

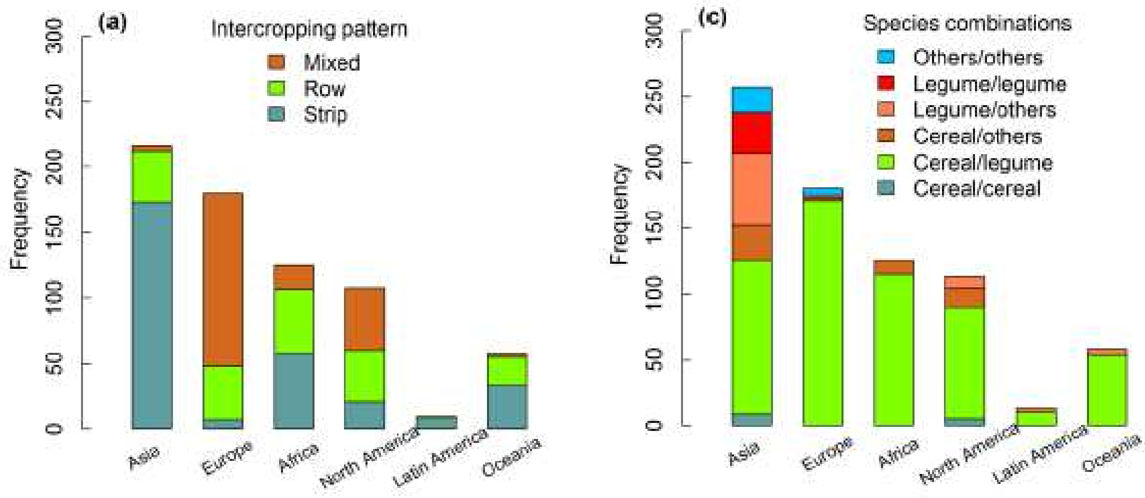


Figure 7: Number of data records in the database used by Yu, Stomph et al. (2015)(In press) related to traits of intercrop systems in different continents: intercropping patterns (a) and species combinations in terms of cereals, legumes and other main groups (c)

As can be seen in Figure 7, mixed intercropping has been the preferred system investigated in Europe; however? and, the mechanization process is done using the existing agricultural machinery (Personal com. Stomph 2015). Interestingly, what the meta-analysis showed is that the temporal niche differentiation can enlarge the LER=? in combination of species such as C4 and C3, which is translated into systems where the stature differences and the different dates for planting and harvesting is desirable from the productivity of land perspective. Such configurations can be either implemented as strip or row intercrops or as mixed intercrops when individual plants are harvested manually.

1.1 Objectives of research on intercropping systems.

According to Connolly, Goma et al. (2001) the concern among agronomists in the light of intercropping research has only focused on issues of yield, the management strategies of / to increase and stabilize yields, and the development of sustainable production systems. This translates in three basic questions that the experiments in intercropping research were trying to answer: 1) which is the more productive mixture. 2) Which species gains in a mixture? In addition 3), how does one species affects another one in a mixture? The indicator most commonly used is the land Equivalent Ratio that measures the efficiency of land use in comparison with the corresponding sole cropping.

Although the issues of yield have led intercropping research, other advantages have been reported such as pest & disease incidence reduction (Andow 1991) in combinations of two species in various spatial configurations. However the results in terms of reduction of pest and diseases can be contradictory and complex at the same time (Lithourgidis et al. 2011)

Yu et al. (2015) addressed the question of what role the time differentiation niche (the time fraction that both species share the field as compared to the whole period) have in the increase of LER among intercropping researched data. It shows that the main motivation for research is still around how to increase LER, which is a land efficiency indicator, which among other things indicates the direction of the future designs to be implemented only from the agro ecological perspective; however, other issues such as the level of used inputs are not explicitly study ied in intercropping research.

2. Features that describe the intercropping systems universe and are interesting from the mechanization perspective.

Space and time complementarities, according to (Willey 1990), are two features of intercropping systems that can broadly explain the complementary usage of resources (water, nutrients and solar radiation), which is normally the motivation of doing applying intercropping systems.

The spatial organization aspect of intercropping systems outlines canopy and/or roots dispersion, which is usually portrayed by distinct intercropped species (e.g. cereals intercropped with pulses, that have difference in both canopy height and root patterns) and its space organization (alternate rows or alternate strips), which allows more capture of resources across the soil and canopy profile. This aspect can definitely influence how the machinery solutions are applied and whether the current machinery can be used it all, because it restricts the space as compared to sole crops where no restriction as for working width has been imposed by the agronomical design.

The temporal synchronization aspect, which portraits the different periods during the growing season when each crop demand resources the most advocate for a more efficient capture of resources timely wise. This aspect can also influence the way machinery for intercrops should be adapted or used because of the fact that both crops share the same field and that different requirements of field operation can occur at the same time.

Consequently, three characteristics can be used that feature spatial and temporal variation (variation that is designed): Strip width configuration, strip width dimension, and time synchronization pattern. These characteristics were considered as important in order to define a concept of intercropping systems that can be assessed from the mechanization perspective.

2.1 Spatial feature: Strip width configuration

Strip width configuration is schematized in

Figure 8. Various reasons might influence the decision of determining the strip with configuration within intercrops. For instance and? optimal capture of light for the system (Biological objective), or a desired ratio of crop A over crop B looking after a specific ratio of products (practical objective) (Willey 1985). From the mechanization perspective, the strip width configuration can determine the

homogeneity for the working width for machinery, or the other way around, the configuration might be adjusted to fit homogenous width among the species.

Figure 8: Schematic transversal section showing two general cases of strip width configuration in intercrops (crop A in Green with 'a' width, crop B in blue with 'b' width)

2.2 Spatial feature: Strip width dimension

The width of the strips can be considered as such as to fit the available agricultural technology when devising a mechanized intercropping system (Vandermeer 1989) or as to optimize the capture of light from the agro ecological perspective Depending on the approach taken in the ecological design, one might have the scenario of current machinery average working width of three meter, where the design criteria are adjusted to the current boundaries of the technology as was studied by Capinera, Weissling, and Schweizer (1985). Alternatively,the approach might be that the technological design criteria fit the optimization from the agro ecological perspective, in a scenario of 1 meter width.

2.3 Temporal feature: Time synchronization pattern

Time Synchronization pattern was defined as the way that intercrops could be designed in terms of start and end of each crop for market or complementary capture of resources. In order to avoid referring to specific sowing dates, as these variables were not the focus of the study, the following time synchronization patterns were defined as depicted in Figure 9 as the possible scenarios whenever a specific combination of annual species are selected as the possible ones.

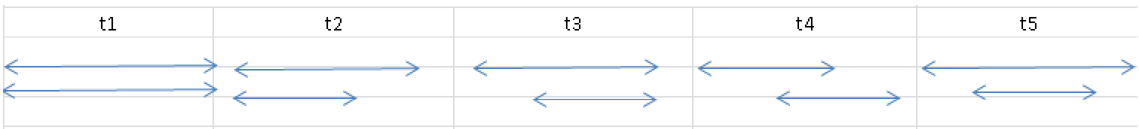
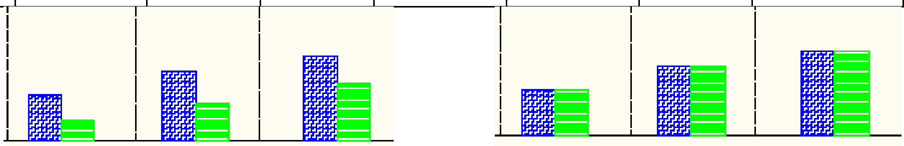
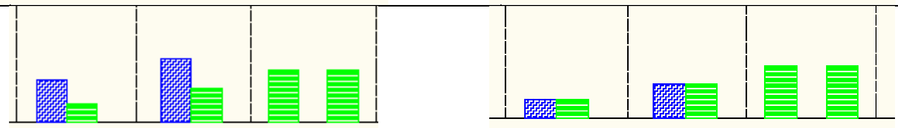
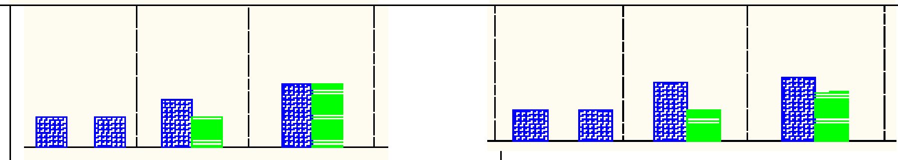
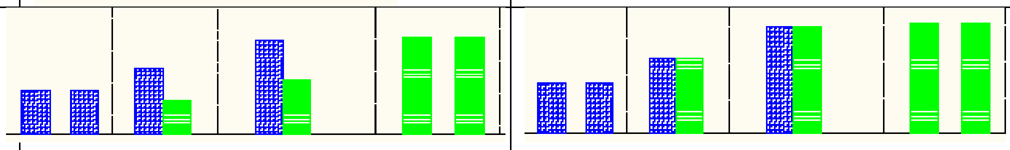
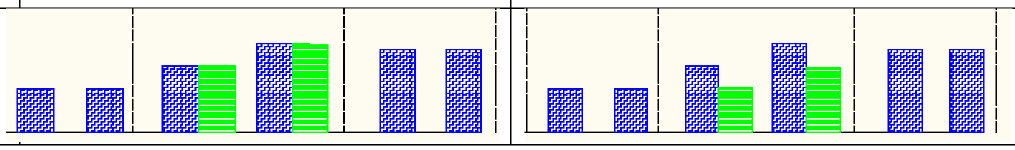


Figure 9: Time synchronization patterns for generic intercrops. Arrows depict the time of growing season for two intercropped species.

Table 1 shows the consequence of each time synchronization patterns in terms of the canopy height of each crop. The relevance for? the mechanization perspective lays in how the machinery might be able to operate considering that crop injuries can be produced while one strip is being intervened and the other has to remain intact.

Table 1: Cross-sectional diagrams that depicts the canopy height of species A (rectangles in blue) and species B (rectangles in green) in two different expected growing season = canopy stages 1 and 2?. TSP=? source?

	Canopy stages 1				Canopy stages 2			
TSP	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
T1								
T2								
T3								
T4								
T5								

3. Demarcation: Strip intercrops as the focus of the analysis for the present report

As for the present report, intercropping systems were conceptualized as strip intercropping regarding the spatial organization aspect, only case w1 regarding strip width configuration (i.e., identical width for both intercropped species) was considered in the light of limited time, however, the other case can be equally used through the methods used in the present report.

Regarding the temporal aspects, two systems that are the synchronous (expressed in T1 see Table 1) and relay intercropping (expressed in T2 see Table 1) were selected. Notice that not all combinations resulting from the mentioned spatial and temporal organization are valid. However, it was beyond the scope of the present study to know in depth the valid combinations of specie's types (e.g. C3 or C4 as for photosynthesis response to temperature, tall and short as for its height, Long or short as for its growing season) which were advantageous to the context of Western Europe.

Since the target system of interest for the present study was the machinery system, and in particular the current machinery principles as the pivotal point, strip intercropping was chosen as the category that defines the concept of intercropping system for the present report. That was chosen for the following reason:

- It was assumed that the first step to implement intercropping systems in the context of West Europe might imply the application of current principles, and it has not happened yet for the case of strip intercropping (aAt least not to a commercial level). This is often seen as a kind of transition state of innovation that might be preferred in order to implement intercropping systems to reduce the investment cost in order to avoid risk adverseness. So the first step is that the spatial organization must suit to the existing concept of agricultural machinery in its very essence, which is performing field activities across a working width (i.e. continuously or alternatively) using a mobile machine that is more productive than a human itself.

- Strips allow having different time synchronization patterns, which is highly probable to expect in intercrops in the context of Western Europe where the growing season is not too long to allow double cropping but long enough to have relay intercropping therefore getting advantages (Yu et al. 2015).

Furthermore, as for the present study, strip intercropping was defined as only two annual arable crops in alternate strips. The assumption made regarding species choice was that the two species must differ from each other in terms of biological features (i.e. root patterns, canopy height, growing period) supported by the scientific evidence that complementarity is pursued when designing intercrops that render some of the reported advantages.

Finally, for the present report, it was chosen to analyze the scenario of three meter width as for the strip width dimension. It was chosen to be a systematic first step to study how the current technological solutions fulfill the functions disregarding the working width limitation. Because suspending it as constraint might reveal the first level of issues that arises from the conception of machinery for intercropping systems using the current technological solutions against a set of objectives in the light of sustainability goals. Additionally, the intention of the three-meter choice was to consider a reasonable width on which the current machinery principles can be virtually implemented, to see the negative interactions among machinery subsystems in terms of the principles they are employing, that would appear at no matter what strip width is in consideration.

3.1.2 Step 2: Define objectives

Figure 10 depicts the objective tree; the first level of generality includes in brackets the actors that are behind the needs. The sub objectives represent the issues as points, the decision of which is of importance to the main objectives.

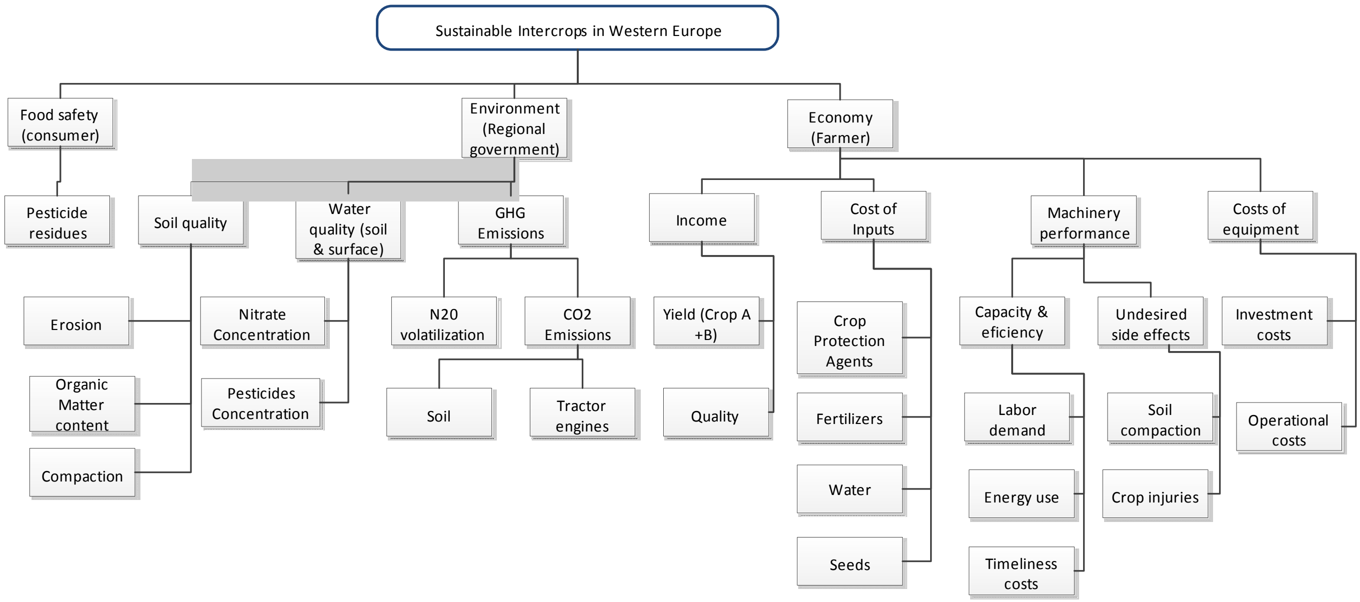


Figure 10: Objective tree for sustainable intercropping system in Europe. Boxes contain selected issues

Actors

Three main actors were identified as to have a stake in the desire situation. The consumer, who buys the produce of intercrops directly (e.g. fresh vegetables, tubers & roots) or indirectly (e.g., dairy products that use forages produced by intercrops); the regional government that refers to the institutions that legislate regulations in agricultural activities; the farmer, who represent the producers that implement intercropping systems.

Consumer needs

The consumer needs to access to safe products in terms of its undesired residues from the production practices. The consumer concerns in relation to food safety has increased as it is proved by the increasing number of independent food safety agencies (van Kleef et al. 2006).

Regional government needs

The regional government, who stands for the 'need' for preservation of natural resources, cares about water, soil and climate change among others. Soil quality, in terms of its human induced erosion, organic matter content, and compaction process involved (Van-Camp et al. 2004). Water quality: in terms of its nitrate and pesticides concentration, which have had adverse impacts in natural ecosystems as well as in the water quality for human consumptions (European commission, water framework directive). Green houses gases emissions in terms of direct CO_2 and N_2O emissions at farm level (European commission, climate change).

Farmer needs

The farmer is the producer that deals with the prospective of changing the arable crop system. His needs are related with the economic aspect of the farm, which is the income received in return of the yield and the quality of the produce. The costs that are involved as for the inputs application, the machinery performance in terms of energy and labor demands plus the ability of performing the operations in a timing manner (timeliness costs), plus the cost of equipment in terms of the investment and the operation of machinery that deal with it.

3.1.3 Step 3: List Requirements

The brief of requirements is presented in Table 2. It was elaborated at two levels. As performance specification for compounded tools from requirement 1-7 (See hierarchal level in Figure 3) (i.e., crop nutrition subsystem, crop protection subsystems, crop irrigation subsystem, and harvest subsystems); and as constraints to the technical installation as a whole from requirement 8 to 17Table 2**Error! Reference source not found.**. These two higher levels in respect to the enlisted requirements were selected in accordance with the structured design approach, which starts from a higher level of generality into lower levels (Van den Kroonenberg 2002).

Table 2: Brief of requirement with its description, variable/indicator, range of acceptability, target value, and its unit.

	Index	Requirement description	Variable/indicator	Min.value	Max.value	Target	Unit
Performance specification for subsystems	1	Application of nutrients should match demands in terms of time and quantity of crop A and B, independently.	Agronomic nitrogen use efficiency for each crop growing period	0.4	0.7	0.7	Kg uptaked/Kg applied
	2	Application of nutrients to crop A should diminish neither yield nor quality of crop B, and vice versa	Reduction in yield by phytotoxicity of nutrient spillover	0	3	0	% as compared to sole crop
	3	Application of Crop protection agent to crop A should diminish neither yield nor quality of crop B, and vice versa	Reduction in yield by phyto-toxicity of herbicides spillover	0	3	0	% as compared to sole crop

	4	Application of Crop protection agents for crop A should not deposit on product of crop B and vice versa	Increment on Rresidues level in neighbor crop product as compared to the Maximum Residues Level of it.	0	2	0	%
	5	Emissions of crop protection agents to the environment should be reduced compared to sole cropping	reduction of measured emissions	0	25	25	% as compared to sole crop
	6	Water should be accessible to crop A and B according to its respective evapotranspiration.	irrigation use efficiency of each crop	0.7	0.9	0.9	Kg up taken/kg applied
	7	Time for harvest operation per kg of harvested product should be equal compared to sole cropping	Variation of Total time/kg of harvestable product operation as compared to sole crops	0	5	0	%
Constraints across all subsystems	8	Machinery should be able to operate in of strip width of 3 meters	-	-	-	-	Qualitativ e
	9	Units labor per unit of harvested product should not be significantly greater than sole crops	Increment of Unit of labor per unit of harvested product as compared to sole crops	0	5	0	%
	10	Combined weight of machinery + inputs/outputs should not reduce yields of intercrops	Yield reduction by short term soil compaction	0	5	0	%
	11	The Return on Investment should be equal or higher as compared to sole cropping system	Increment of ROI as compared to corresponding sole crops	0	5	5	%
	12	Combine weight of machinery + inputs/outputs should not produce soil compaction in the long term	Increment of Sub-soil compaction as compared to undisturbed soils	0	5	0	%
	13	Soil Organic matter levels should be maintained according soil type	Organic matter content (soil type dependent)	3	8	8	%
	14	CO_2 foot print on products should be equal or lower than sole crops	Reduction in direct emissions of CO_2 per unit of harvested product as compared to the current situation.	0	20	20	%
	15	Machinery operation of crop A should not harm the canopy of crop B	Photosynthesis reduction of neighbor crop	0	1	0	%
	16	Machinery operation of crop A should not harm the roots of crop B	Damage of roots neighbor crop	0	1	0	%
	17	Machinery should be able to operate in scenarios of strip width of 1 meter.	-	-	-	-	-

3.1.3.1 Requirements 1-7 performance specification for compounded tool or machinery Sub systems.

Requirement 1: Application of nutrients should match demands in terms of time and quantity of crop A and B, independently.

Rationale

Agriculture has increased the availability and the mobility of nitrogen at regional and global scale even though the application of it is done at a local level (Vitousek et al. 1997). The issue of surplus of nitrogen can ease the eutrophication process, which can be measured in the nitrate concentration of surface or underground water is required to be controlled in its source both for economics and environmental concerns (Alcoz, Hons, and Haby 1993). In the case of the future sustainable intercropping system, nitrate concentration of surface and underground water is a concern as for the application of nitrogen to the system. Consequently, matching the supply (i.e. application of nitrogen by the crop nutrition sub-system) and the demand of nitrogen (i.e. crop demand of nitrogen) in terms of quantity and time defines the boundaries of what is acceptable. The requirement assumes that application of nitrogen is expected to remain imperative because intercrops will deplete soil nutrients faster than sole crops, due to a complementary of root systems (Willey 1990), therefore the supply of nitrogen would be desirable to keep the yields and quality of products coming from intercropping systems.

Indicator and range of acceptable values

Agronomic uptake efficiency was selected as the indicator, which is measured as the kg of nitrogen taken up over the kg of nitrogen applied. The range of acceptable values was set on 0.4 – 0.7. (Alcoz, Hons, and Haby 1993) studied the effect of application rate and timing of fertilization of nitrogen for wheat and found that there was possible to reach the range of acceptable values of 0.4 - 0.7 by splitting the total application rate in fractions, so it was assumed as an indication to evaluate the agronomic uptake efficiency

Table 8. Effect of nitrogen fertilizer application rate and timing on apparent fertilizer nitrogen uptake efficiency by wheat.

Timing	1989	1990 75 kg N ha^{-1}	1990 150 kg N ha^{-1}
		%	
All preplant (pp)	40.1b†	37.0b	19.0a
vs.			
Split applied	65.0a	58.0a	19.9a
2 split applications	57.3b	60.0a	17.2a
vs.			
3 or 4 split applications	72.5a	65.0a	22.6a
2 splits, 1:1 pp/GS4 or 6‡	58.1a	37.0b	13.6a
vs.			
2 splits, 1:1 pp/GS10	55.9a	78.9a	18.5a
2 splits, 1:1 pp/GS4	51.7a	22.7b	14.5a
vs.			
2 splits, 1:1 pp/GS6	64.5a	51.3a	18.7a
3 split applications	68.8b	61.0a	20.4a
vs.			
4 split applications	80.0a	73.3a	27.2a
3 splits, 1:1:1 pp/GS4/GS6	68.9a	46.1b	16.3a
vs.			
3 splits, 1:1:1 pp/GS4/GS10	68.8a	75.9a	24.4a

† Within years, rates, and contrasts, means followed by the same letter are not significantly different at $P = 0.05$.
‡ GS, growth stage according to the Feekes scale (Large, 1954).

Requirement 2: Application of nutrients to crop A should diminish neither yield nor quality of crop B, and vice versa

Rationale

Growing intercrops in strips implies that roots of both crops can reach the same soil regions (borders) - inducing roots interactions that can change root patterns (Miyazawa et al. 2010), and canopies are in the same open air. Applying nutrients will necessarily pass through soil or air. Therefore, an unintended spillover-effect can possibly cause reduction of yields or the quality of products if two selected crops have contradictory needs at the same time regarding its nutritional demands.

Indicator and range of acceptable values

Reduction in yield by phytotoxicity of nutrient spillover was selected as an indicator. Phytotoxicity can be induced by Cu, Zn, and NH4+-N, all of which can be produced during composting of pig manure (Tiquia, Tam, and Hodgkiss 1996). That can serve as an indication that using certain fertilizers when applied to intercrops can lead to reduction in yields for the neighbor crop. The range of acceptable values was rather arbitrary based on the assumption that a reduction of 3 % in one of the component crops equals a margin of error for any solution applied.

Requirement 3: Application of Crop protection agent to crop A should diminish neither yield nor quality of crop B, and vice versa

Rationale

Following the rationale for requirement 2, the application of crop protection agents must pass through soil and air as well. The spillover of it from crop A to B and vice versa is expected to happen, however, what is required as for the protection system for intercrops is to avoid a reduction in yield or quality of the neighbor crop.

Indicator and range of acceptable values

The indicator selected was reduction in yield by phytotoxicity of herbicides spillover. The reason under that choice was to portray the most challenging situation using the current agricultural practices to intercrops, the spillover of herbicides which has been mentioned as the main problematic situation when mechanizing intercrops (Lithourgidis et al. 2011); (Erbach and Lovely 1976).

The range of acceptability was equally determined arbitrary aiming at a maximum reduction in yield of 3% to the neighbor crop. That is considering that crop A and B were conceptualized as two distinct species such as cereals and legumes, which are thin and broad leaf respectively and are contradictory as for the biochemical mechanism of action for selective herbicides.

Requirement 4: Application of regulated crop protection agents for crop A should not deposit on product of crop B and vice versa.

Rationale

Following the rationale of requirement 2 Applying crop protection agents (contact or systemic products) regulated by the European food safety directives can be deposited on or in neighboring crop products elevating the pesticides residues on or in it. Therefore, is required that cross depositions are reduced, from the food safety of consumers perspective.

Indicator and range of acceptable values

"A maximum residue level (MRL) is the highest level of a pesticide residue that is legally tolerated in food or feed when pesticides are applied correctly (Good Agricultural Practice)" (European Commission 2015).

Increment on Residues level of crop protection agent in neighbor crop product was selected as the indicator as compared to the Maximum Residues Level of it. The acceptable range was set on 2 percent increment of residues level as compared to the maximum. Although the consequence of allowing the maximum residues level to be incremented will directly contradict the requirement, it was intentionally meant to see the extent of drift on pesticides expected with the current solutions and then to see which adaptations are needed.

Requirement 5: Emission of Crop protection agents emission to the environment should be reduced compared to sole cropping

Rationale

Emission for crop protection agents to the environment are required to be controlled. For instance, pesticides and fungicides have had a negative impact on biodiversity of wild species and its biological control potential in European farmland (Geiger et al. 2010). In addition, already in the 1960's the negative effects of pesticides and fungicides to aquatic organisms were recognized as a result of runoff from agricultural fields (van der Warf 1996).

Indicator and range of acceptable values

The indicator chosen was rather generic one: reduction of measured emissions. Measured emissions can be seasonal losses by runoff or leach of surface soil pesticides, drift of sprayed crop protection agent and volatilization of it (van der Werf 1996). Why is 25 % a sufficient goal?

Requirement 6: Water should be accessible to crop A and B according to its respective evapotranspiration.

Rationale

Each crop has its particular evapotranspiration daily values, therefore a specific crop dependent supplement of water is required in order to keep the yield of intercrops as high as possible, as well as avoiding leakage of nutrients and pesticides.

Indicator and range of acceptable values

Use efficiency as the ratio between kg of water taken up by the plant and kg of water applied through irrigation. The range of acceptable values was determined as 0.7-0.9.

Requirement 7: Time for harvest operation per kg of harvested product should be equal compared to sole cropping

Rationale

Timeliness of operation was defined as the ability to perform an activity at such a time that quality and quantity of products are optimized (van Elderen 1977). Timeliness costs for the harvest operation means that a harvestable product has a window of opportunity when its value is maximized in response to climate factors and market prices, if that period is missed; the value will be diminished translating into reduced income. Therefore, the requirement aims at not surpassing significantly the current total time for a harvest operation, assuming that the current machinery principles have aimed at reducing the total time in a very effective way.

Indicator and range of acceptable values

Increment of total time for harvesting operation per kilogram of product as compared to sole crops was chosen as the indicator to measure the timeliness performance of current machinery principles in the harvest operation. A target of 0% increment and a maximum of 5% were selected as the acceptable range

3.1.3.2 Requirements 8-17 related to constraints across the whole system

Requirement 8: Machinery should be able to operate in of strip width of 3 meters

Rationale

The strip width of 3 meters was required in order to recreate the scenario 1, on which the preference for the existing working width will play an important role in the technology users as for a transition state of innovation.

Requirement 9: Units labor per unit of harvested product should not be significantly greater than sole crops

Rationale

Labor as an input has a significant impact on Return on Investment in the context of arable farming sector in Europe, it is desired to keep the labor input low as possible when compared it to the current situation.

Indicator and range of acceptable values

The indicator used was the percentage of increment in terms of unit of labor per unit of harvested product. In this way, the indicator accounts for the activities that are perform during the completely growing season, giving the chance to adjust the usage of labor across the different field activities so to have a balance. A range of acceptable values was set upon 0-5% accounting for a margin of increment that may occur in intercrops, however can be compensated with the expected higher income corresponding to the expected higher yields of intercrops.

Requirement 10: Combined weight of machinery + inputs/outputs should not reduce yields of intercrops

Rationale

According to a review made by (Hamza and Anderson 2005) the factors that have caused soil compaction and therefore reduction in yields within intensive agriculture, are the load on soil from farm machinery or livestock. The signs of over-compaction can be found along wheel tracks and on the turning strips at field edges and are more severe on the topsoil.

Indicator and range of acceptable values

The indicator selected was percentage of yield reduction due to short-term soil compaction, since the expected assessment of current technological solutions certainly include the traction by wheels on the field. The range of acceptable values was again proposed to be as from 0-5% in order to recognize intentionally the possible increment on traffic lines due to the restriction of space.

Requirement 11: The Return on Investment should be equal or higher as compared to sole cropping system

Rationale

A relevant requirement for a new machinery system was consider being that it can be perceived as adoptable by its main users: north European farmers. One relevant aspect that influences the decision to adoption largely is the economic one. According to Musshoff and Hirschauer (2008) the models that explain reluctance to conversion from a conventional farm system to an organic agriculture take into consideration the following aspects of the adoption process: 1) the temporal rate of diffusion of adoptions of new technologies 2) non-monetary goals, which is related with keeping with traditions 3) Risk aversion, on which farmers expect a premium in order to take a risk translated into a higher cost explain the low conversion rates 4) low gross margins after conversion, reflecting that the higher prices obtained with organic agriculture might not overpass the extra cost of investment and those related to the learning process.

Indicator and range of acceptable values

As the author cited in the above section, the indicator that probably influences the most when it comes to a conversion in the technological realm is the Return on investments. The target value was set on 5 % increment when compared to sole cropping and the range of acceptable values from 0-5 %, which means at least equal or higher return on investment.

Requirement 12: Combine weight of machinery + inputs/outputs should not produce subsoil compaction in the long term.

Rationale

There is evidence that topsoil compaction is related to ground pressure while subsoil compaction is related to total axle load independently of ground pressure (Hamza and Anderson 2005). Subsoil compaction is a problem that can cause soil erosion and surface water pollution by increasing its runoff. Therefore, the compaction of subsoil is a concern from the environmental point of view: soil quality and water quality are link by the increased chances of water runoff. The corresponding variable that is related to the machinery system is how the weight of machinery + inputs and outputs is distributed to the soil causing subsoil compaction.

Indicator and range of acceptable values

The indicator was again set as the increment when comparing to the undisturbed soils, being the target of no increment and the range of acceptable values to be that of 5%, in order once again to give chance to error to occur, considering that traffic will occur anyway.

Requirement 13: Soil Organic matter levels should be maintained according soil type

Rationale

Reducing soil organic matter content implies emissions of CO_2, since the dynamics SOM are linked with the C cycle, when the SOM is accumulating it results in a capture of Carbon and when it is reduced it results in a emission of CO_2 along other emissions such as NO_3 and N_2O (Van-Camp, Bujarrabal et al. 2004)the later which is a very powerful greenhouse gas. Therefore keeping its optimal level can target several objectives at the same time.

Indicator and range of acceptable values

The soil organic matter content as is was chosen to be the indicator of its quality. The range of acceptable values is dependent on its capacity to be retained in the soil as a function of the soil type and the climatic conditions. That is why in the range of acceptable values was set from 3 % until 60%

Whatever the solution is considered regarding machinery operation, it implies a motion of tools through the intercropping field, either to place inputs or to harvest outputs. The issue is to keep the canopy of intercrops as functional as possible.

Requirement 14: CO2 footprint on products should be equal or lower than sole crops.

Rationale

The emission of CO_2 provoked in the process of combustion of energy by the machinery that perform field activities is required to be reduced in the desired situation by the society.

Indicator and range of acceptable values

The indicator selected was the reduction in direct emissions of CO_2 per unit of harvested product compared current situation. The target value was chosen to be 20% since it that value was set as the target of reduction in the GHG in the European union by the 2020, since Agriculture was estimated to be responsible for 35% of emissions (Ovando and Caparrós 2009).

Requirement 15: Machinery operation of crop A should not harm the canopy of crop B

Rationale

The execution of field activities into one crop might have an adverse impact in the neighbor crop due to damage in its canopy by mechanical forces or due to residues that deposit on the leaves. This is an assumption based on the possible damages that the current technology might cause because of impact of the implement of the 4-wheel tractor against the neighbor canopy.

Indicator and range of acceptable values

The indicator was chosen to be the photosynthetic reduction perceived by the neighbor crop because of mechanical damage that can affect the yields. The target was zero reduction in photosynthesis activity as compared to a healthy crop and the acceptable range was set to 1% acknowledging that the effect of plant injuries by mechanical forces has not being study as such in the literature available. However one can argue that an issue like that is easy to solve, but it needs to be point it out as an essential requirement when it comes to intercrops.

Requirement 16: Machinery operation of crop A should not harm the roots of crop B

Rationale

Similarly as the requirement 15, the execution of field operations in one crop can damage its neighbor's roots by the forces applied by the tillage implements or its tire pressure on the borders. Because the roots expand in every direction, the borders between two crops can be

Indicator and range of acceptable values

Similarly, to the requirement number 15, the indicator was chosen to be the expected roots damage in the border zone and the target to be at zero and the acceptable range of values up to 1%

Requirement 17: Machinery should be able to operate in scenarios of strip width of 1 meter

Rationale

From the agro ecological perspective, more interaction is produced when the strip width is reduced. Inthe particular situation when the closer interaction provides moremore advantages of intercropping systems, the machinery should be able to operate in the presupposed width of around 1 meter. It was determined for the present report as a desirability in terms of requirements nature, which means that not critical for the evaluation of the solutions.

3.2 Analyze Functions

3.2.1 Step 4: Analysis of Generic arable crop system

In Appendix 2, the complete IDEF0 model for a generic arable crop system is presented. The context diagram is presented in Figure 11, which describes all the inputs, outputs, mechanism, and controls of the model. The model represents the arable crop system whose person main objective is to produce either food or feed at the field gate.

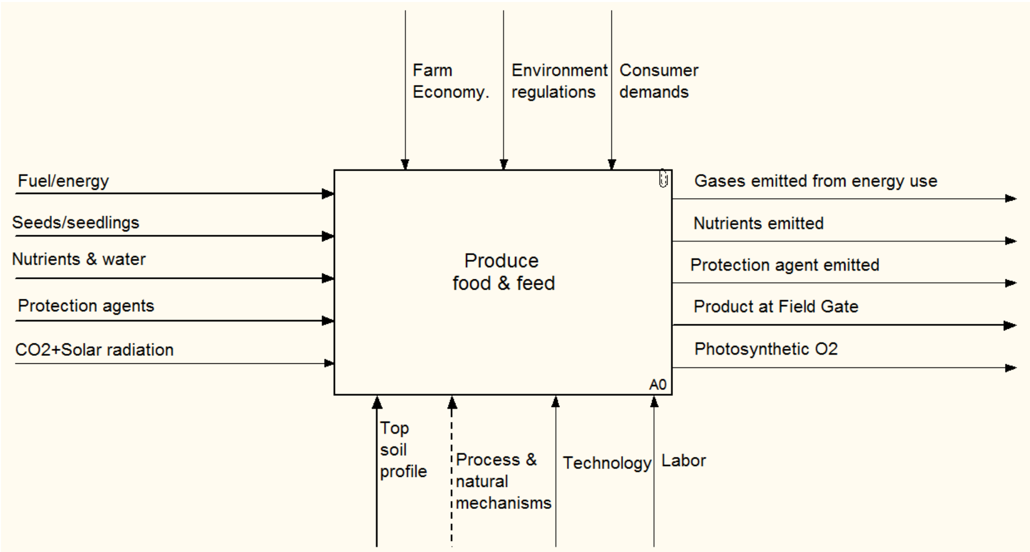


Figure 11: Viewpoint of functional analysis boundaries functional diagram of an intercropping/sole cropping production system.

Establish crops, provide nutrients & water, protect crop and harvest crop were correspondent to the conventional field operations within the cultivation process and were established as first level functions. Figure 12 shows the first level with functions and their relations in terms of inputs and outputs of a generic arable crop system.

Producing biomass by the plant species was represented by the function 'Grow crop A+B'. Two crops were included in that function as to portray either a conventional system with two crops at different fields, or a strip intercropping system. Both systems realize the functions in first level, however, controls and mechanisms could vary when comparing both. For instance, the technology employed to protect crops might differ in the final configuration as for mechanizing sole crops or intercrops, although in principle they could be the same.

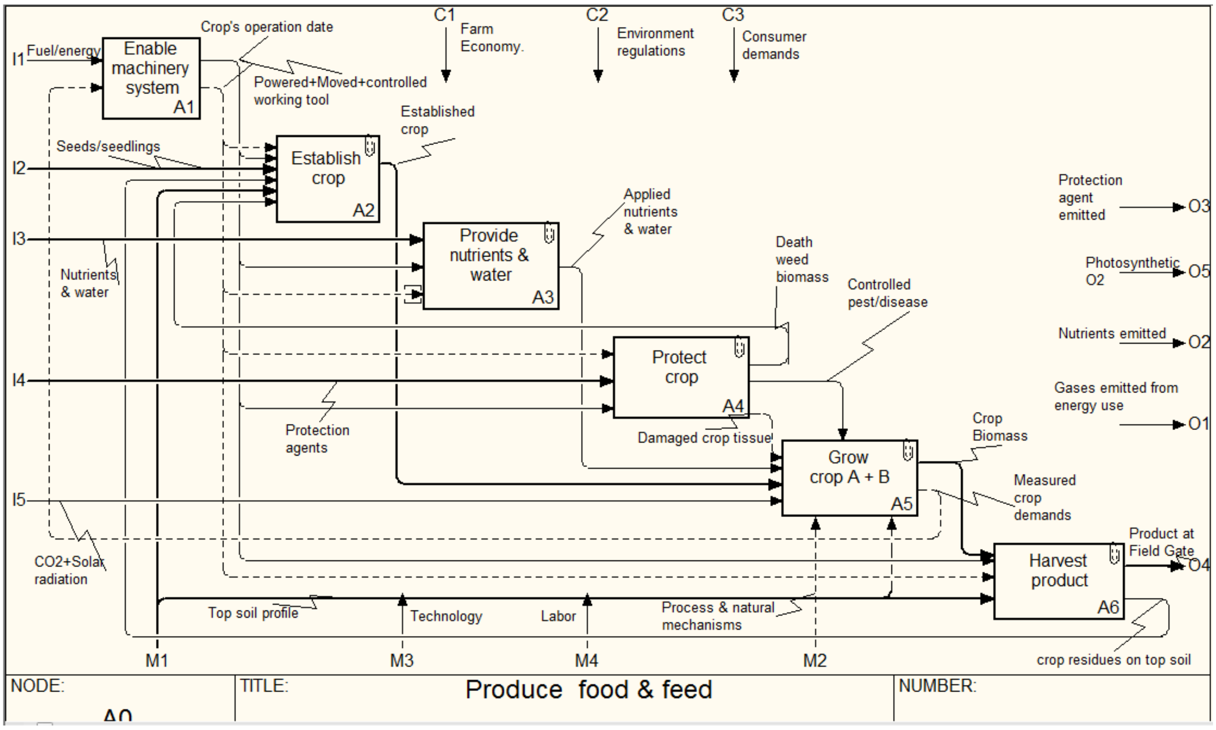


Figure 12: IDE0 diagram as for the first level of functions of a generic arable crop system

Enable machinery system was founded as essential function at the first level of the model, since its outputs include firstly the schedule of field the operations (see Figure 13:IDEF0 diagram of 'Enable machinery system as crop operation date), which represents tactical decisions based on specific information and constraints (i.e. crop demands as information and climate window of opportunity or timeliness costs as constraints). Secondly, after scheduling, the machinery has to be put into action, represented in abstract terms by the function 'enable working tool' and its output 'powered+moved+controlled working tool', which were found to be essential to farming operations no matter what level of technology is applied (e.g., manual tools, animal draught tools, modern machinery equipment).

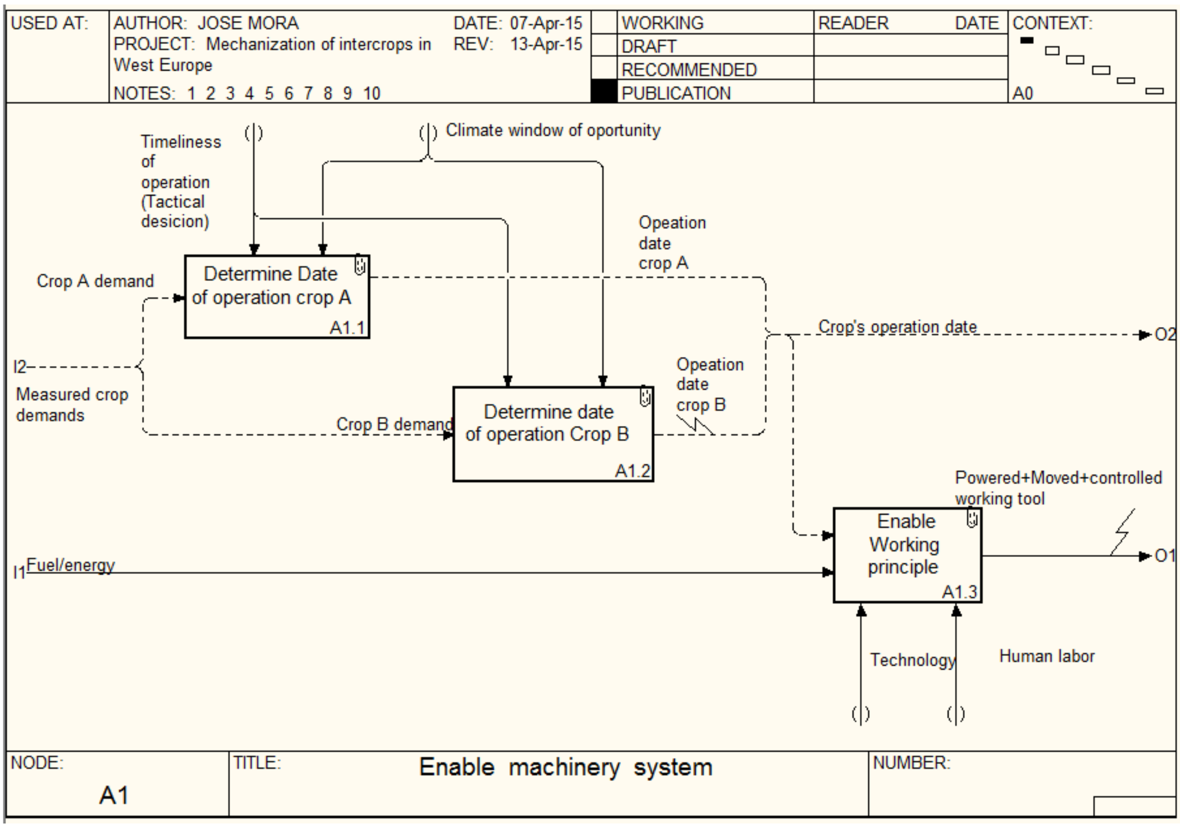


Figure 13:IDEF0 diagram of 'Enable machinery system' first level function

Either sole crops or intercrops have the same functionalities. However, the difference between them can be recognized whenever both crops need an operation to be executed at the same time, hence, the considerations to be taken might differ. In the case of sole crops it becomes a problem of resources allocation, given that a limited amount of equipment or labor force are available at the farm in a particular moment (van Elderen 1977). In the case of intercrops, it may involve a conflict that can potentially result in risk of damage to the other crop in terms of root, canopy, or produce. For instance, crop protection operation in one crop can be demanded at the same time that harvesting the other one. One good example of it is the next figure that depicts the different crop demands in terms of operations needed among three categories of crops along four seasons in the context of the Netherlands (de Veer et al. 2014) .

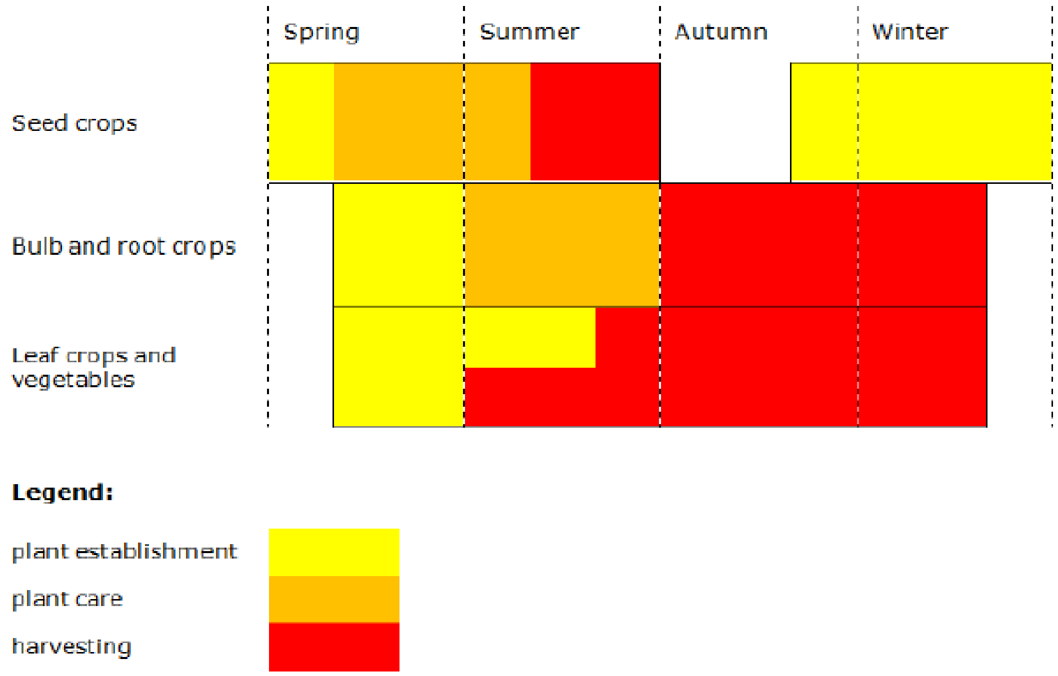


Figure 14: Crop cultivation calendar. The types of operations in their temporal context for different crop types are shown. Copied from: (de Veer et al. 2014)

In Figure 15 the functional diagram of enable working principle is presented. Abstracted form the current technological solutions, the sub functions that produce the output powered+moved+controlled working tool were modelled as to represent the technological devices, the inputs and the constraints that every machinery system must include. It was by purpose located in the diagram the requirements elaborated that act as conditions and constraints in the case of intercropping systems.

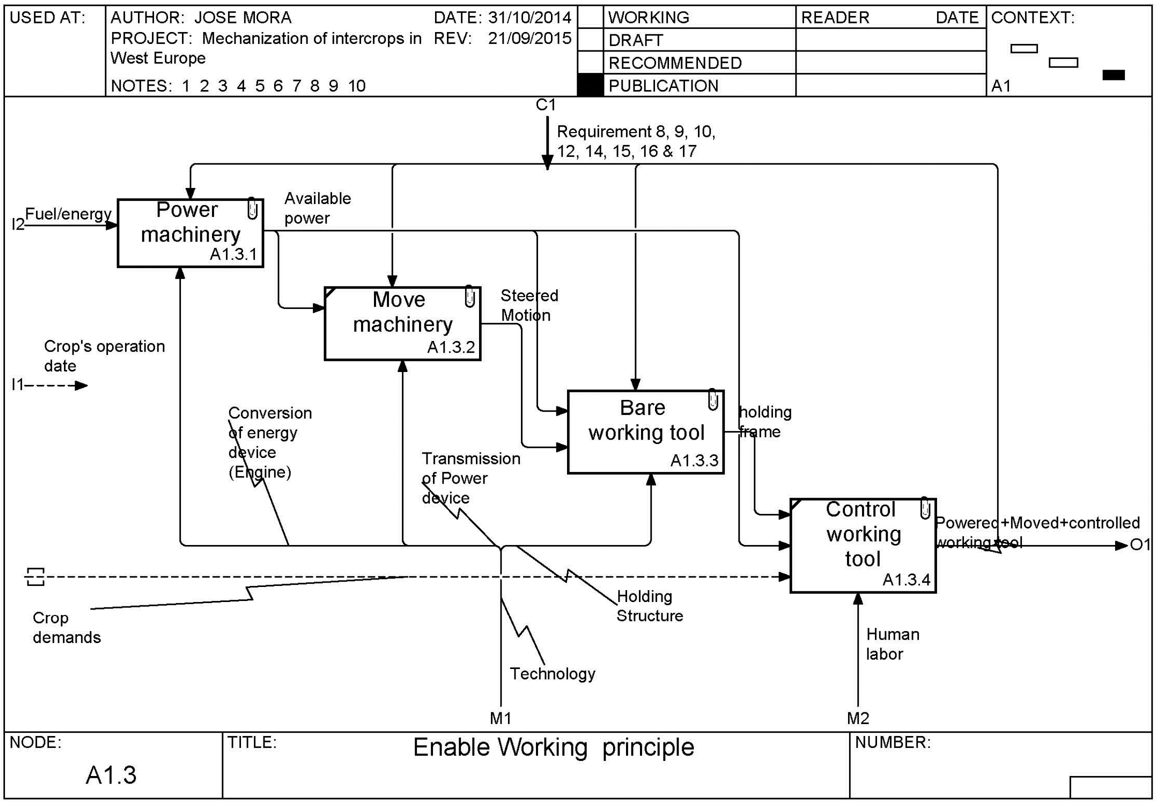


Figure 15: Functional diagram of the sub function: enable working principle

Table 3 and Table 4 present all functions and correspondent sub-functions identified in the IDEF0 model for a generic arable crop system without indication of their relations between each other, however useful to look at them all.

In addition to the previously mentioned first level functions, 'Measure crop demands' was identified as a function that entail all the sub functions that measure the crop demands that are expressed as information needed to perform the other first level functions (i.e. plant nutrient demand, soil's nutrients availability, product maturity state, and so on).

Table 3: Functions and sub-functions extracted from the IDEF0 model

Function	Sub-function 1	Sub-function 2
Establish crops	Prepare seed/seedling bed	Process soil &residues
		Loosen the soil
		Form bed
	Plant seeds/seedlings	Store seeds/seedlings
		Convey seeds
		Meter seeds
		Make furrow/hole
		Place seed
		Close furrow/hole
		Firm soil

Provide nutrients	Determine quantity + location of nutrient demand	
	Apply solid nutrients	Store solid nutrients
		Meter solid nutrients
		Convey solid nutrients
		Place solid nutrients
	Apply liquid nutrients	Store liquid mix
		Keep liquid mix
		Convey liquid mix
		Place liquid nutrients
Provide water	Determine water status demand	
	Apply water	Store water
		Meter water
		Convey water
		Place water
Protect crop	Control weeds	Separate weeds from its roots (option 1)
		Bury weeds (option 2
		Poison weeds (Option 3)
	Control pest & diseases	Choose protection agent
		Store protection agent
		Transport protection agent
		Place protection agent
Grow crop A + B	Grow crop A	
	Grow crop B	
	Measure crop demands	Measure soil nutrient availability
		Measure plant nutrient demand
		Measure water at field capacity
		Measure plant transpiration rate
		Measure weed infestation
		Measure pest & disease incidence
		Measure crop product's maturity state

Source: Appendix 2

In Table 4, the function harvest product is presented as a first level containing the tree generic products from annual crops that might be included in intercropping systems: grains, roots, and leafs. The three products have different sub functions, which were abstracted from the current machinery principles. Interestingly, it allows designing new concepts by splitting the functionalities.

Table 4: Harvest product function and its sub-functions

Function	Sub-function 1	Sub-function 2	Sub-function 3

Harvest product	Get product	Get grain	Cut
			Thresh
			Separate
			Clean
		Get cleaned roots	Cut shoots & leaves
			Get roots out of soil
			Sieve roots
			Separate roots
			Clean roots
			Return soil
		Get leafs	Separate above biomass
			Clean product
	Transport target product		
	Store target product		
	Return crop residues		

Source: Appendix 2

3.2.2 Step 5: Select key functions for intercrops

The key functions that have a significant role in realizing the brief of requirements were the following.

- ***Provide nutrients****:* requirement 1 (indicator range: 0.4-0.7 kg N uptake/kg n applied) might be met with the current solutions (for instance by splitting the application rates in several times during season). However, at the same time solutions for this requirement can potentially contradict requirement 2 (range: reduction in yield by nutrient spillover 0-3%) and can contradict requirement 10 (range: yield reduction by short-term soil compaction) because of more traffic lines.
- ***Protect crop:*** requirement 3 (indicator range: max!!! 0-3% reduction in yield by phytotoxicity of herbicides spillover) and requirement 4 (indicator range: max? 0-2% increment in MRL of neighbor crop) might not be met by the current application technology of herbicides and pesticides, which is using drop-type sprayers on the canopy.
- ***Provide water:*** Requirement 6 (indicator range: 70-90% kg of water uptake/kg applied) might be met with current solutions (drip irrigation). However, it might contradict requirement 11 (Increment of ROI compared to sole cropping) due to the extra investment in irrigation installations.
- ***Harvest product:*** Requirement 7 (indicator range: max 0-5% increment in total time/kg of harvested product as compare to sole crops) might not be met by the current solutions in harvesting arable crops because of restrictions of space imposed by some of the time synchronization pattern (see Figure 9) where one strip might be harvested while the neighbor would be growing.
- ***Move machinery:*** in order to meet the requirement 10 & 12, the essential function move machinery can radically affect how the solutions meet the requirement, specially considering that with a restricted working

width such as strip intercrops, an increase in the traffic lines can occur and is desirable to be kept at minimum

In table 6 the contradiction matrix is presented

A=adaptation needed

C= Conflictingfunction behind

Table 5: Matrix of contradictions between brief of requirements

REQUIREMENTS																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1		A	-	-	-	-	-	-	C	C	C	C	-	C	C	-	-
2			-	-	-	-	-	-	C		-	-	-	-	C	-	-
3					C	-	-	-	C	-	-	C	-	-	-	C	-
4					-	-	-	-	C	-	-	C	-	C	-	-	-
5						-	-	-	-	-	-	-	-	-	-	-	-
6							-	-	C	C	C	C	-	C	C	-	-
7								A	A	A	C	A	-	C	C	C	A
8									A	C	-	C	-	C	C	C	A
9										-	-	-	-	-	-	-	-
10											-	-	-	-	-	-	C
11												-	-	-	-	-	C
12													-	-	-	-	C
13														-	C	-	-
14															-	-	C
15																-	A
16																	-
17																	

3.2.3 Step 6: identify new functions

As for the analysis done in the light of demarcation, new functions for intercropping systems were not identified. Since one purpose of doing strip intercropping is to allow independent cultivation of crops within the same field, what was different when comparing to a functional analysis of a sole crop was the constraints to be faced in the form of brief of requirements, which were identified in the IDEF0 diagrams as can be seen in the Appendix 2.

3.3 Analyze solutions

3.3.1 Step 7: List current technological solutions, machinery principles overview

As the basis, the function analysis was used to investigate the current machinery solutions for arable farming operations.

Table 6 elaborates the analysis from the main function to its sub-functions in a hierarchal manner; the current available solutions were picked up from the commercial equipment and from prototypes that are being developed. In that way the current technological elements can be split up in order to visualize their purpose.

Table 6: list of current technological solutions and its characteristics/configuration for function: enable machinery system.

Function	Sub-function 1	Current tech. solutions	Characteristics/configuration
Enable machinery system	Power machinery	Diesel engine	Agricultural tractor = Engine + gear box + 2 axles final drives; Self-propelled agricultural vehicle
		Electrical engine	
		Co-generated engine	
	Move machinery	2 wheel traction	
		4 wheel traction	
		Track laying traction	
		Control traffic (applicable to the previous 3 solutions)	
	Bare working tool	Rear/front mounted (MER/MEF)	Implement = soil engaging devices, storage component, distribution device
		Rear/front semi mounted (SER/SEF)	
		Towed	
		Gantry system/wide span system	Gantry system= engine + drive wheels + implements
		Self propelled equipment	Self propelled equipment = SP harvester, SP transplanter, SP sprayer, robot weeding platform
	Control working tool	Human operator	Located ahead the implement: for soil tillage implements, distribution devices Located behind the implement: for harvesters.
		Autonomous / automatically controlled system = not an autonomous system yet	

Table 7 presents the main function of establishing crops and its current technological solutions. Mainly, the soil preparation is done with multiple tools that were set into soil engaging devices that can use a combination of several mechanical principles and are commercially available tillage implements. As for the function plant seeds/seedlings even more sub functions are performed at one pass with the current configuration.

Table 7: list of current technological solutions and its characteristics/configuration for function: Establish crops.

Function	Sub-function 1	Sub-function 2	Current tech. solutions	Characteristics/configuration
Establish crops	Prepare seed/seedling bed	Process soil &residues	Incorporating residues (inverting land)	Operator + A.Tractor + Soil engaging devices
			Mulching (cover soil)	

		Loosen the soil	Vertical tillage (Applied in Autumn)	
			Horizontal tillage (Applied in autumn)	
		Form bed	Flat top bed former	
			Ridger	
	Plant seeds/seedlings	Store seeds/seedlings	Drill seeder, singulating planters, singulating planting tubers, autonomous transplanters	Operator + A. tractor + storage component + soil engaging device + distribution device; SP trans planter
		Convey seeds		
		Meter seeds		
		Make furrow/hole		
		Place seed		
		Close furrow/hole		
		Firm soil		

Table 8 presents the current technological solutions for a complex function such as provide nutrients. Remarking that the sub functions of measuring soil nutrient availability and plant nutrient demand can be done using precision agriculture sensor, which might be of great importance as for intercropping systems, where the more precision of measurements is needed whenever a more precise application of nutrients is desired as in intercropping systems.

Table 8: list of current technological solutions and its characteristics/configuration for functions: provide nutrients and provide water.

Function	Sub-function 1	Sub-function 2	Current tech. solutions	Characteristics/configuration
Provide nutrients	Determine quantity and location of nutrient demand	Measure soil nutrient availability	Concentration of soil nutrients sensors	Precision Agriculture sensors, sensing the reflectance of soil
		Measure plant nutrient demand	Leaf stalks petioles sampling method	Sampling procedure
			Crop Nitrogen stress sensor	Precision Agriculture sensors (Crop nitrogen stress)
	Apply solid nutrients	Store solid nutrients	Fertilizer rotary spreader (after planting); drop-type banded spreader (during or after planting)	Human + A. tractor + storage Component + (soil engaging device) + distribution device
		Meter solid nutrients		
		Convey solid nutrients		
		Place solid nutrients		
	Apply liquid nutrients	Store liquid mix	Drop-type liquid sprayer; Manure injector	operator + A. tractor + storage component + (Soil engaging device)+distribution device; SP sprayer
		Keep liquid mix		
		Convey liquid mix		
		Place liquid nutrients		
Provide water	Determine water status demand	measure water at field capacity	Sampling measurement instrument	
		Measure transpiration rate	Models	
	Apply water	Store water	Drop-type liquid sprayer; furrow irrigation; sprinkler	Operator + A. tractor + storage component + distribution
		Meter water		

		Convey water	irrigation; drip irrigation	device; irrigation equipment
		Place water		

\

Table 9 present the crop protection function as to be implemented in various components of current technological solutions. As for measuring the infestation of weeds and the diseases incidence, precision agricultural sensors can add high value to the current technological solutions, since now it is possible to deliver more precisely the information about where disease are located increasing the efficiency of application.

Table 9: list of current technological solutions and its characteristics/configuration for function: protect crop.

Function	Sub-function 1	Sub-function 2	Current tech. solutions	Characteristics/configuration
Protect crop	Control weeds	Measure weed infestation	Digital Image analysis devices; Mapping weed	bi-spectral camera + image processing component
		Separate weeds from its roots (option 1)	Mechanically inter-row	Human+ Tractor + Soil engaging devices
			Mechanically Interplant	
		Bury weeds (option 2	False seed bed (Two tillage operations)	Human+ Tractor + Soil engaging devices
		Poison weeds (Option 3)	Selective herbicide drop-type sprayer	Human + tractor + storage + Distribution device
	Control pest & diseases	Measure pest & disease incidence	Sampling methods; prediction models; precision agriculture sensors	Experimental stage of sensing specific site discrete patches
		Choose protection agent	Preventive and curative protection agents	
		Store protection agent	Drop-type sprayer; site specific biomass drop-type sprayer	Human + A. tractor + storage component + distribution device; Human + SP sprayer
		Transport protection agent		
		Place protection agent		

Table 10 presents the function harvest product as it is fulfilled by the current technology. In all of the considered products for annual species, the current configuration implies a concept which perform various sub functions in one pass, such as the combine grain harvester, the sugar beet harvester, the mobile processing unit, In all these concepts the functional process of harvesting is performed by one single machine in one pass, which in the other hand relies in the transportation of the produce out of the field to not be restricted. However, in the light of intercropping systems, there likely will be space restrictions

Table 10: lList of current technological solutions and its characteristics/configuration for function: harvest product.

Function	Sub-function 1	Sub-function 2	Current tech. solutions	Characteristics/configuration
Harvest product	Get grain	Cut	Combine grain harvester	Operator + SP harvester
		Thresh		
		Separate		
		Clean		
	Get cleaned roots	Cut shoots & leaves	Roots and tubers harvesters	Operator + SP harvester;
		Get roots out of soil		
		Sieve roots		
		separate roots		
		clean roots		
		Return soil		
	Get leafs	Separate above biomass	Vegetable harvester	Operator + A.tractor + Hharvesting implement; mobile processing unit
		Clean product		
	Transport target product	Load to transport	Transporter along the harvester	Operator + A.Tractor + storage component
		Taxing the field		
		Unload the product		
	Store target product			
	Return crop residues		Combine grain harvester	human + SP harvester

Be consistent with capitals in the table

3.3.2 Step 8: Assessing current technological solutions

The assessment was based on the brief of requirements and the functional analysis. The former defined a quantitative assessment, which is the current machinery was scored against the list of requirements. The list of requirements was matched with the function analysis from there; the following subsections will elaborate the assessment in terms of its main activities.

The assumption made prior to the evaluation was that the intercropping system to consider in the assessment was that of three meter width strip intercropping, according to the demarcation made in section 3.1.1.2

For requirement 1 & 2.

For requirement number 1, according to the interviews, as to have an independent application of nutrients to crop A and B did not get to the target value, although it was found as technically feasible, the mean score given to the requirement was 3.25. This meant that the target might not be reached using the current solutions. However, the coefficient of variation among the answers was 29% indicating different opinions about the same matter (See Table 11).

According to the rationale of the interviewed people, at first glance, the current technology in respect to the fertilization of Nitrogen appeared to them as plausible to get near the target. The problem nevertheless, was that they did not have a clear understanding of the indicator itself. After making clear that in average the 0.5 ratio of uptake/application is a normal value in current situation, the assessment was changed to a less optimistic value but with still within the range of acceptability (i.e. 0.4-0.7 kg uptake/kg applied for the whole season)

For the requirement number 2, there was a more optimistic assessment of the performance of current solutions in order to avoid nutrient phytotoxicity by a nutrient spillover to the neighbor crop. The remark that arises from the interviews in that particular matter suggested that, in practice the choice of species would be done in a smart way as to avoid conflicts between nutrient demands of the intercropped species that might cause reduction of yields by phytotoxicity. However, the fact that a spillover of nutrients to the neighbor crop during the application using the current technology was confirmed as possible, but the harmful consequences of it were not regarded as a major problem.

Table 11: Result of assessment of current technological solutions for requirement 1 and 2

Index	Requirement description	Fixed Req.	Variable req.	Desirability	Variable/indicator	Min.value	Max.value	Target	Unit	Mean Scale (0-1-5)	SD	CV
1	Application of nutrients should match demands in terms of time and quantity of crop A and B, independently.		x		Agronomic nitrogen use efficiency for each crop growing period	0.4	0.7	0.7	Kg uptaked/Kg applied	**3.25**	**1.00**	29%
2	Application of nutrients to crop A should diminish neither yield nor quality of crop B, and vice versa		x		Reduction in yield by phyto-toxicity of nutrient spillover	0	3	0	%	**4.00**	**1.15**	29%

Req. #	Fixed Req.	Variable req.	Desirability	Variable/indicator	Min.value	Max.value	Target	Unit	Mean Scale (0-1-5)	SD	CV
1		x		Agronomic nitrogen use efficiency for each crop growing period	0.4	0.7	0.7	Kg uptaked /Kg applied	**3.25**	**1.00**	29 %
2		x		Reduction in yield by phytotoxicity of nutrient spillover	0	3	0	%	**4.00**	**1.15**	29 %

In Table 12, the current functions that need to be improved were assessed in order to reach the target value for the two requirements concerning the application of nutrients, taking as basis the interview answers.

The function Measure plant nutrient state, is currently done in various ways. Investigating what is the average practice in arable crops sector in Europe was not part of the study. Furthermore, the answers obtained in the interviews represented perceptions of a particular cases of the farming sector in the Netherlands, thus cannot reflect a valid sampling framework neither within the country nor at the regional level.

Although technological solutions exist in order to improve the functionalities expressed in the Table 12, the implementation in the current arable system was reflected by the "+++" score as lacking. That is, the '+++' score points out a higher relevance of improvements within 'measurement functions' than in functions related to the application itself (i.e. place solid nutrients and place liquid nutrient).

A remark was made that operating current machinery in strip intercropping systems is possible, not only considering as such but as new machinery that would add functionalities such as strip specific outflow of liquid or solid fertilizers in order to perform operations for both crops at the same time whenever is possible.

Table 12: Quantitative assessment in terms of scope for improvements of technical solutions for each related function ('+'=1-2; '++'=3; '+++'=4-5. Scale 1=little room for improvements, 5=lot of room for improvements) Room for improvements in order to meet the target value of requirement

Sub-functions	Requirement number 1	2
Measure plant nutrient state	+++	++
Measure Ssoil nutrient availability	+++	++
Calculate external nutrient demand	++	++
Place solid nutrients	+	+++
Place liquid nutrients	+	+++

As for the question whether the current solutions can meet the requirements, the main finding was that, independent application is possible, but the accuracy of it may have to be improved by more specific devices that can incorporate nutrients site specific wise.

The development of new sensor technology for site specific nutrient management will provide the accuracy that is needed in providing nutrients for two crops in the same field aiming at improving the efficiency use and the emissions reduction. According to Heege (2013), there has been developed sensing technics for soil and crop properties with a resolution of 100 signals per hectare, which can be regarded as potentially useful for strip intercropping nutrition provision.

For crop protection, requirements 3,4 and 5

As can be seen in Table 13, the current solutions were scored as capable of meeting the variable requirements. In the case of reduction of yields by herbicides spillover, all the interviewed persons confirmed that even with the most precise technics, undesired drift for herbicides will occur if that solution is applied and hence a reduction of yield within 0-3% range was expected. However, since the requirement is to avoid a reduction of yield and quality, the other solutions (as presented in Table 8) can be applicable to intercropping; thus, the reduction of yields by herbicides can be minimized. In other words, using the current options solutions / technical principles in a smart way the requirement can be met, and that is why coefficients of variation of answers was 58% exposing different appreciation of how other solutions can be combined in order to avoid herbicides spraying.

Nevertheless, the requirement is focus on avoiding negative effects to the neighbor crop by assessing its chances to get damaged by using the current technology, neglecting the fact that not controlling weeds as effectively as herbicides can render a reduction in yields in the target crop in the first place.

As for the requirement 4, which aims to / is aiming at avoid deposition of undesired residues of crop protection agents on neighbor crop, the answers had aa mean score of 1.75 with 55 % of variation coefficient. The rationale for scoring current technology within the acceptable values for an intercropping system was that the choice of species has to play a role in reducing the application of crop protection agents therefore reducing the drift of it and the corresponding deposition.

As for requirement 5, the answers agreed pretty much in getting close to the target of reducing the measured emissions to the environment even using the current technology with no increase in the level of accuracy. In a similar rationale as the previous assessment, the application of current technology was put aside in order to reduce the measured emissions, giving to the right combination of species the main mechanism to achieve that target for intercropping systems. Furthermore, one remark made by one interviewed explained that the emissions resulted by drift of pesticides while depositing in the neighbor crop it might at the same time reduce emissions to the environment and increase the level of residues on or in the neighboring crop.

Table 13: Result of assessment of current technological solutions for requirement 3, 4 and 5.

Index	Requirement description	Fixed Req.	Variable req.	Desirability	Variable/indicator	Min.value	Max.value	Target	Unit	Mean score (0-1-5)	SD	CV
3	Application of Ccrop protection agent to crop A should diminish neither yield nor quality of crop B, and vice versa		x		Reduction in yield by phytotoxicity of herbicides spillover	0	3	0	%	**2.00**	**1.15**	58%
4	Application of Crop protection agents for crop A should not deposit on product of crop B and viceversa	x			increment on Residues level in neighbor crop product as compared to the Maximum Residues Level of it.	0	2	0	%	**1.75**	**0.96**	55%
5	Crop protection agents emission to the environment should be reduced compared to sole cropping				reduction of measured emissions	0	25	25	%	**4.00**	**0.00**	0%

Table 14: Quantitative assessment in terms of scope for improvements for each related function ('+'=1-2; '++'=3; '+++'=4-5. Scale 1=little room for improvements, 5=lot of room for improvements)

Sub-functions	Requirement number		
	3	4	5
Measure weed infestation	+	+	+
Measure pest & disease incidence		+++	++

Place protection agent	+++	+++	+

For crop irrigation requirement 6

First refer oto the table …The answers were within the acceptable range with an average of 2.25 and the coefficient of variation of 71% expressing different interpretations of what is possible to reach with current technics. However, the target was impossible to reach according to the interviews. This corresponds with the very nature of water content in the soil and crop which is a transient property that can vary drastically within hours depending on weather conditions (Heege 2013a). The development of sensing technology that will increase the measurement accuracy of water content in the soil will play a major role in increasing the efficiency of application, that is important from the yields perspective and also from the environmental perspective because of water infiltration with pollutants.

Table 15: Result of assessment of current technological solutions for requirement 6.

Index	Requirement description	Fixed Req.	Variable req.	Desirability	Variable/indicator	Min.value	Max.value	Target	Unit	Mean Scale (0-1-5)	SD	CV
6	Water should be accesible to crop A and B according to its respective evapotranspiration.		x		irrigation use efficiency of each crop	70	90	90	Kg uptake /kg applied	**2.25**	**1.60**	**71%**

For crop harvest requirement 7

As for the harvesting crop, the next table shows the main concept solution to realize the three main functions: get, store and transport. In order to get the target product a sequential process is performed almost simultaneously namely, cutting, separating and cleaning it. It was conceived as to deliver a clean product to a transporter vehicle that carries it out of the field continuously completing the harvest operation as fast as possible.

In relation to requirement number 7, the target of 0% increment in the total time per kg of harvested product was regarded as not possible using the current solutions, a mean score of 2 with cv. 41%. The reasons behind the answers laid in the standard size of harvester machines in the Netherlands, which are capable of working within strips of three meters width except for grains (combine harvesters wider working dimensions). Thus, the increment in the total time, was regarded to fit the 5% range for acceptability in the requirement definition, as to portray the average result considering different types of crops such as roots, tubers or leafs.

Table 16: Result of assessment of current technological solutions for requirement number 7

Index	Requirement description	Fixed Req.	Variable req.	Desirability	Variable/indicator	Min.value	Max.value	Target	Unit	Mean Scale (0-1-5)	SD	CV
7	Time for harvest operation per kg of harvested product should be equal compared to sole cropping		x		Variation of Total time/kg of harvestable product operation as compared to sole crops	0	5	0	%	**2.00**	**0.82**	41%

The main limitation has to do with transport the target product once it is obtained by the harvester.

Table 17: Quantitative assessment in terms of scope for improvements for each related function ('+'=1-2; '++'=3; '+++'=4-5. Scale 1=little room for improvements, 5=lot of room for improvements)

Sub-functions	Req.# 7
Get product	++
Store target product	+
Transport target product	+++

For cost aspect: labor demand and investment cost for equipment, requirement 9 & 11 respectively.

Requirement 9 and 11 relate to the cost aspect of the machinery system. The assessment involved all subsystems at once. Both mean scores showed that the requirements can be met by the current technology according to the answers. Preparing seed bed was scored as little room for improvement, since there is no significant distinction between the current labor input in strip intercropping and the comparable sole cropping. On the other hand, the crop protection sub-system as well as the harvest subsystems will play a major role in incrementing the number of hours.

Table 18: Result of assessment of current technological solutions for requirement 9 and 11. Bottom part quantitative assessment in terms of scope for improvements for each related function ('+'=1-2; '++'=3; '+++'=4-5. Scale 1=little room for improvements, 5=lot of room for improvements)

Requirement number	9	11
Requirement description	Units labor per unit of harvested product should not be significantly greater than sole crops	The Return on Investment should be equal or higher as compared to sole cropping system
Variable/indicator	Increment of Unit of labor per unit of harvested product as compared to sole crops	Increment of ROI as compared to corresponding sole crops
Min.value	0	0
Max.value	5	5
Target	0	5
Unit	%	%
Mean Score (1-5)	**3.25**	**2.25**
C.V	**46%**	**76%**
function		
Prepare seed bed	+	+
Provide nutrients	++	+++
Protect crop	+++	++
Provide water	++	+
Harvest crop	+++	+++

For soil compaction aspect: requirement 10 & 12

As Figure 16 summarizes, several parameters in relation to the field operations by agricultural tractor intervene in soil compaction. However, wheel contact pressure mainly causes soil compaction in the upper layers of soil whilst wheel total load does in the lower layer under tractor tracks (Kitani 1999).

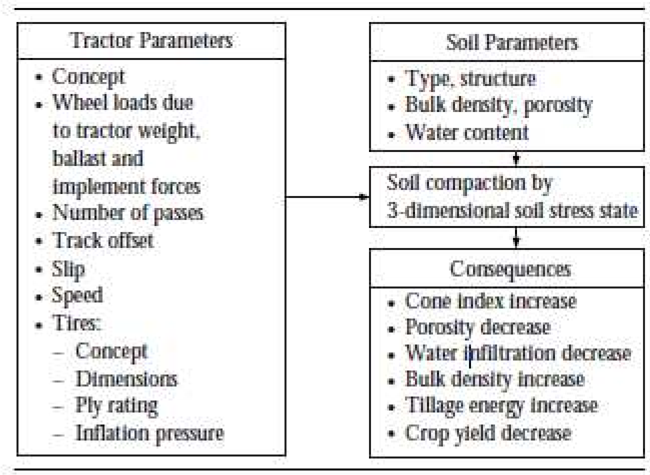


Figure 16: Soil compaction parameters

Source: (Kitani 1999)

The number of passes itself has an impact on soil compaction, even if a light tractor is run for a number of passes over the same tracks, there is a threshold after which the impact on soil compaction is greater than the impact of fewer passes with a heavier tractor (Jorajuria and Draghi 2000).

Hence, reducing width of operation can increase soil compaction in the field by increasing the number of traffic lines per area. Lighter machinery can reduce the surface compaction but only within a limited range of passes.

Results from interviews

The mean score as is / be shown in Table 19 show that the requirement can be met within the acceptable range, however the variation among the answers were 47% and 53%. The arguments among the interviewed students were that more traffic lines per area will be done in intercropping systems but at the same time less passes through the same lines are expected because less protection agents are assumed to be needed in intercrops, thus, translating that expectation into a ecological design criterion.

Table 19: Result of assessment of current technological solutions for requirement 10 and 12. Bottom part quantitative assessment in terms of scope for improvements for each related function ('+'=1-2; '++'=3; '+++'=4-5. Scale 1=little room for improvements, 5=lot of room for improvements)

Requirement number	10	12
Requirement description	Combined weight of machinery + inputs/outputs should not reduce yields of intercrops	Combine weight of machinery + inputs/outputs should not produce soil compaction in the long term
Variable/indicator	Yield reduction by short term soil compaction	Increment of Sub-soil compaction as compared to undisturbed soils
Min.value	0	0
Max.value	5	5
Target	0	0
Unit	%	%
Score (1-5)	**3**	**3.25**

C.V	47%	53%
functions		
Prepare seed bed	+	+
Provide nutrients	++	++
Protect crop	++	+
Provide water	++	+
Harvest crop	++	+++

For CO_2 emissions aspect, requirement 14.

According to the interviews, the requirement of reducing the CO2 emissions using current machinery principles in a generic intercropping system can be expected to be in the acceptable range with a score of 3.25 and C.V of 46%. The interpretation that led to that average followed a similar logic as previous considerations: intercropping systems will necessarily reduce the total amount of inputs application as compared with sole crops. This can have two implications; firstly, less work to do in absolute terms (i.e. less weight to carry, less number of protection agent applications); secondly, probably longer periods to perform that work (i.e working width restriction to three meters reduce field capacity of current machinery principles to certain operations) that might need less energy per hour of operation.

Table 20: Result of assessment of current technological solutions to meet requirement 14. Bottom part quantitative assessment in terms of scope for improvements for each related function ('+'=1-2; '++'=3; '+++'=4-5. Scale 1=little room for improvements, 5=lot of room for improvements)

Requirement number	14
Requirement description	CO2 foot print on products should be equal or lower than sole crops
Variable/indicator	Reduccion in direct emissions of CO2 per unit of harvested product
Min.value	0
Max.value	20
Target	20
Unit	%
Score (1-5)	**3.25**
C.V	**46%**
Function	
Prepare seed bed	++
Provide nutrients	++
Protect crop	++
Provide water	++
Harvest crop	+++

Room for improvements in respect to reducing emission was pointed mainly in the current harvest crop subsystem.

3.3.2.1 Adaptations for current technological solutions

Adaptations will occur at various levels, in the methods used by the present research the problems were undercover in a qualitative and quantitative manner, giving rise to the discussion of what approach to proceed regarding the innovation needed, because none of the details that would requires a more precise design were known. However, in the present section we present our findings in terms of what generally will be the response to certain problems the new designs have to tackle.

Crop nutrition technology

Adaptations needed

- Improve the measurement capacity of the machinery system in terms of plant nutrient state and soil nutrient availability, considering two distinctive crops in the same field.
- Adaptations are required in terms of how to calculate external nutrient demand for both crops by acknowledgment of the border zone between the two species intercropped may differ as from the independent zone.
- Improving the precision of nutrients application (Solid and liquid) throughout the season, considering that unintended negative spill-over effects might happen in intercrops and that difference in canopy height among strip intercrops might limit the application of some type of equipment such as the configuration identified as operator + A. tractor + storage Component + (soil engaging device) + distribution device. Therefore, designing new technological solutions in terms of new nutrient application equipment capable of operate throughout all the season without problems of traffic along the strips; or in terms of special designing new coating to solid fertilizers that allows a very slow release of nutrients.
- Another relevant adaptation has to be done in order to meet the requirement of no increment on labor input as well as operational costs, and that is to redesign the equipment as to keep the same field capacity but with a differentiable distributions of nutrients among the strip intercropping species.

Crop protection current technology

Adaptations needed

- Improvements in the precission application of herbicides are expected if the target value of 0% reduction in yields is wanted to be achieved in strip intercrops.
- Oher strategies, such as including in the ecological design criteria of intercrops, improvements in the weed management by reducing its pressure, can avoid the usage of herbicides in intercropping systems in the first place.
- Improvements in measuring the pest and disease incidence and its precision on application are desired in order to meet the requirement 4, which was related to the cross deposition of crop protection agents in the products.

- Selecting the species to be intercropped in a smart way in order to reduce emissions by the reduction of the level of crop protection agent use, was found to be a desired ecological design criterion, according to the interviewees.
- Another relevant adaptation has to be done in order to meet the requirement of no increment on labor input as well as operational costs, and that is to redesign the equipment as to keep the same field capacity but with a differentiable distributions of crop protection agent among the strip intercropping species.

Harvest technology

New solutions needed

- New solutions have to be found by redesigning the current technology for transport the products out of the field using the current machinery principles of combined harvesting process applied to strip intercropping systems. That solution is needed if the requirement of 0% increment in harvesting duration is wanted to be achieved from the timeliness cost perspective.
- The problem of increase usage of labor using the current machinery principles can be dealt with automation of current machinery or with the automation of small scale harvesters (Schetters 2014)
- The problem of increment in long-term compaction lead by more traffic lines in strip intercrops regarding the harvest operation needs to be solved. As (Schetters 2014)concluded, small scale autonomous solutions might reduce the soil compaction and increase yields.
- In order to reduce the CO_2 footprint with20% (Target value for req. 13) the current machinery principles regarding the harvest operation need to be improved, because is expected that the field capacity will be reduced in strip intercropping and therefore increasing the expenditure of energy. Probably by optimizing the transport of products out of the field, the field capacity can be kept as the same as in sole crops. However that does not mean a reduction of 20% in direct CO_2 emissions, which poses a very difficult goal to achieve.

4 Discussion

The discussion is presented by recalling the research questions formulated for the present report.

How can we derive a valid demarcation to intercropping systems in order to analyze the technological aspects of mechanization in the context of Western Europe?

The methods used in the present report allowed a systematical demarcation of the target system that was subject to analysis. The three-circle chart rendered the identification of true objects and subjects at different levels that may influence the technological aspect of the mechanization of intercropping systems. The main subjects identified were the farmer, the consumer, and the regional government; because they may have interest in the way technological devices intervene in the production process of agricultural goods, according to the analysis and the literature cited in sections 3.1.3. and 3.1.23.1.2. De Veer, J. et al. (2014) used the three circle chart to analyze intercropping systems. They include the manufacturers of agricultural equipment and scientist as subjects that have a stake in the implementation of intercropping systems in the context of North Western Europe. As for the present study, the limited time available elude the inclusion of other relevant subjects in further steps of the analysis, such as the manufacturers of agricultural machinery or the operators of agricultural machinery. They certainly may have interest in the technological aspects of mechanizing intercrops.

The second part of the demarcation step, allowed searching for features found in intercropping systems research that might influence the machinery design criteria at a principle level. Spatial and temporal features of intercrops as they were conceptualized in the demarcation step are likely to be found in real and advantageous systems. That means spatial configuration of 3 to 1 meter strip width and temporal synchronization (T1 and T4). Considering those as features that can also outline the challenges from the technological perspective was a useful first systematic step to investigate mechanization of intercropping systems, because those features demarcates the first level of challenges to be lifted by new machinery to intercropping systems in a generic way. However, the choice made in order to delimitate the present report, which was to take only the strip intercropping of three meter width as the first step, might produce different results in the assessment step compared to the alternative of taking strip intercropping width of 1 meter, in some of the requirements used in the present report. Nonetheless, the tendency of the variables that measure the requirements to be expected in the scenario of 1 meter width, are possible to know by using the logics behind the answers of the interviewed people and the literature found. It could show some expected conflicts in relation to:

- Increment in energy use
- Increment in soil compaction
- Increment in labour use
- Increment in harvest operation time

Those conflicts are expected to happen using the current machinery principles whenever the field capacity is reduced as was confirmed by the interviewees. Consequently if using the current machinery principle are desired to be implemented, the adaptations or redesigns of machinery have to tackle the enlisted issues. Using the current information available such as that found in Schetters (2014), he claims that there might be competitive solutions in the small scale autonomous technology regarding beet harvesting process in relation with some of the enlisted points above. First, that technology will not increase the labor input. Secondly, it can reduce the compaction as compared to the current situation of big and heavy machines in the case of harvest operation. Thirdly, it will be competitive in terms of profitability by using other transport units that can speed up the harvest process while incrementing the yields because of less damage to soil by heavy machinery.

The actual value of analyzing a scenario of 3 meter width for strip intercropping disregards the agro ecological design goals, of increasing the species interactions at the biological level (Looking for increment in productivity of land) and might look at the scenario of 3 meter as non-optimal. However, from other agroecological goal perspective In (Capinera, Weissling, and Schweizer 1985), the intercropping system tested for was a combination of strips of sweet corn and pinto beans, which objective was to reduce the pest abundance. Results showed that the pest reduction effect of strip width did not contradict the dimensions required to mechanize field operations using existing machinery at the time. They decided to investigate the mechanization aspect on purpose, having again in mind the approach of considering the machinery aspect more or less as a fix condition for real implementation, as far as they studied, the goal of reducing the incidence of pest can be deal with a strip width of 3 meter.

Finally, it is useful to recognize that using the current machinery principles in narrower strips does not change the adaptations needed enlisted in section 3.3.2.1 in relation to the crop nutrition and crop protection technology adaptations, since those adaptations are needed in order to avoid conflicts between to species in the same field regardless of its spatial configuration. Whether those same machinery principles can be implemented in new small machinery from the technical feasibility point of view is a different question that goes beyond the scope of the analysis and the methods used.

- What goals and requirements are needed in order to realize a sustainable intercropping system?

The goals in terms of objectives for intercropping systems and its correspondent brief of requirements for the machinery system were determined according to the demarcation step. Acknowledging of needs through exploration of secondary information allowed supporting the objectives presented in the present report without surveying the actors directly that would have implied more time that was not available.

In the present study an objective tree was elaborated in order to structure the needs in terms of issues that might be considered if the desired situation were to be realized. However, other stakeholders not considered in the tree such as manufacturers of agricultural equipment, inputs suppliers, or the operators of machinery, might have also valid issues to be considered in the light of the research questions that would have enlarged the answers to it. For instance, the field challenges of performing a particular operation to only one crop without damaging the neighbor might imply extra-precision that the machinery operator have to comply. In order to enable that, other adaptations or innovations to current machinery might be needed, as to acknowledge the needs of the operator of having a safe work environment that limits the stress of it.

Whenever formulating a brief of requirements, to enlarge the solution space has to be the purpose, in order to evaluate a new design (Ooster and Vroegindeweij 2013). Interviewed students considered the present brief of requirements as a tool to evaluate current technology in the light of a new design, where actually the ecological design criteria support the achievement of requirements giving them a vision of a co-design of technological and ecological solutions. The later can be proven by the results the interviewed students gave to it regarding requrement 5, about the reduction of emissions to the environment. They scored the current solutions as to be in the acceptable range assuming that the selection of intercropping species should be done in such a way that less crop protection agents must be needed so the system can reduce the emissions enlarging the solution space as to include the biological aspect of intercrops. Therefore, in further research the biological aspect of intercrops should be included as an important component of the whole system that has to be define as requirements.

- What functionalities are playing a role in future machinery for intercrops in the light of sustainability goals?

The IDEF0 method of functional analysis proved to be useful to decompose the arable crop system and to distinguish between functions and solutions (i.e. between abstract structure and concrete structure). For a generic crop system, functions were found to be composed of agricultural inputs (e.g physical or information), mechanism in technological and biological terms, and the requirements in terms of constraints and performance specifications. Functions were essentially the same when thinking in terms of a generic crop system and a strip intercropping system. That is clear if one understands that one of the purposes of strips is to allow the cultivation of each crop independently from the other when it comes to perform the field activities.

Other key functionalities may appear as critical in the analysis of more complex systems, such as the case of row and relay intercropping, where and independent cultivation is hardly possible, but it could actually be considered as dependent cultivation. From that point of view the current key functionalities such as provide nutrients and protect crop, will play a role in the design of mechanical solutions but, further sub-functions are needed to be identified as critical in order to meet the target value of requirements set upon the current analysis.

What are the shortcomings of the current machinery principles when they applied to intercrops that can be adapted or redesigned?

The adaptations that are needed to the current technological principles identified in step 8 of the current report for the demarcation done in step 1, applies for many specific strip intercropping systems regardless of the species selection and the exact strip width. Authors that discuss or investigate the mechanization aspect of intercropping systems, considered the mentioned aspect more or less as a fixed factor that has to be accounted. The following cases are explored and discussed in terms of results of the present report.

Erbach and Lovely (1976) simply claim that no relevant problems would rise from mechanizing strip-intercropping systems using the machinery working width by the time existing not surprisingly, pointing out the major problem with undesired effects of herbicides spraying. That issue has still to be addressed in the current state of technology. However, they have an assumption implied in such statement that the approach to solve mechanization of intercrops is to adapt the ecological design towards the current machinery dimensions and configurations that might not yet be optimal to either perspectives, ecological and technological.

In the case of strip intercropping of leek and celery in the Netherlands, it was confirmed that mechanization did not present a technical difficulty using existing machinery. That was an element that farmers appreciated during field trials (Baumann, Bastiaans, and Kropff 2001). However, they did not explicitly claim that the agro ecological design should have fitted the existing machinery for field operations; it was an intrinsic condition for its formal assessment on experimental fields. The results showed that the main problems originated from the quality of the produce as influenced by interspecific competition between the two species. The mechanization aspect was not a priority, however, they conceive the system having in mind independent cultivation with existing technology, which meant mechanical planting and harvest operations, and that can only be done with strip intercropping in order to introduce machinery in the system.

In (Capinera, Weissling, and Schweizer 1985), the agro ecological design was tested to determine its adaptability within the boundaries of existing technology. The intercropping system tested for was a combination in strips of sweet corn and pinto beans, which objective was to reduce the pest abundance. Results showed that the pest reduction effect of strip width did not contradict the dimensions required to mechanize field operations using existing machinery at the time. They decided to investigate the mechanization aspect on purpose, having again in mind the approach of considering the machinery aspect more or less as a fix condition for real implementation.

(Yadav 2013) shows howdesigning seeding and fertilizing equipment for inter-row intercropping is already possible with the current technology that is a seed-cum fertilizer drill attached to a tractor and viable for various seed sizes, rates, and inter-row distances, in the context of India. The new equipment however, just enables a proper crop establishment in terms of plant geometry and fertilizer application for a legume and non-legume inter-row intercropping, two elements that balance competition and increase productivity according to their literature review. However, harvest and grain separation, as well as weed control was not even mentioned as a source of a problem, which one can assume that is done manually in which case mechanization is not compulsory in that particular context and not completely valid to compare with the context of West Europe.

On the other hand, (CLEMSON EXTENSION, n.d.)They proposed for the context of southern United States as for relay intercropping of wheat and soybean inter-seeder equipment that enables the establishment of soybean while wheat is still in the field using a control traffic approach. That might be seen as co-design process, where the agro ecological perspective is integrated within the boundaries of the technology. For instance, the space configuration (Space between strips and rows) of Wheat was designed to allow a control traffic concept and an inter-row seeder that can provide several purposes: preserve soil (Control traffic), increase the productivity of land (Higher LER), and reduce herbicides application (less weed pressure). Still, current technology for doing sole crops was used in principle since the same tractor was used and only the inter-seeder had to be designed accordingly, while getting advantage of the relay intercropping which actually improves the traditional double cropping system.

That brings to differentiate two different approaches to the conceptualization of innovation in the system, where the agro ecological perspective adjusts to the boundaries of the current technology in order to ease the process of transition between the current sole cropping systems into intercropping ones. The other approach would be to co-design the intercropping systems from the mechanization and from the agro ecological perspective, considering the needs of various stakeholders such as farmers, equipment's manufacturers, harvester contractors, machinery operators, soil and agro ecological scientists.

5 Conclusions

System analysis approach and review on the literature can be used as methods to demarcate intercropping systems in the perspective of technology for mechanization within a scarcity of real cases.

The structured design approach was selected to identify the objectives in order to realize a sustainable intercropping system. In that exercise, the stakeholders involved were assumed to have needs that express in issues to be solved such as the issue of how the farmers increase yields while reducing agricultural inputs; or the issue of how to preserve soil and water quality from the society perspective. By clarifying the issues that stakeholders face, the objectives were set upon a higher level of generality, at economy of the farm, the food safety of consumers and the environment preservation objective of the regional government.

The key functionalities that will play a role in future machinery design can be synthetized as sensing intercrops, provide nutrients, protect intercrop, harvest intercrop, move working tool. More detailed sub functions will appear if the intercropping system at consideration is more complex than strip intercropping systems.

Independent and precise application of inputs namely nutrients and crop protection agents to component species of intercropping systems play an important role in the adaptations of current machinery.

The current machinery configuration can face problems in the harvest operation for intercropping systems; those problems are likely to be found in the logistics of transporting products out of the field. It is problematic if the soil compaction and labor demands are to be reduced.

6 Recommendations

Survey the needs of actors not included in the present research that might have a stake as part of intercropping system.

Include more features of intercrops to study more precisely the feasibility of current technological principles in future designs.

Study the feasibility of current engineering principles when they are applied to its very limit, in other words to know what is the minimum working width that current technology can be implemented in.

Research in intercropping systems has to start to co-design the system as a whole considering the technology of mechanization and the agro ecological efficiency. Including more resources, conservation objectives would add even more value in order to create attraction to the stakeholders that might be involved in future projects.

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Appendixes

Appendix 1: Brief of requirements with its variables/indicators and values and relation with objectives

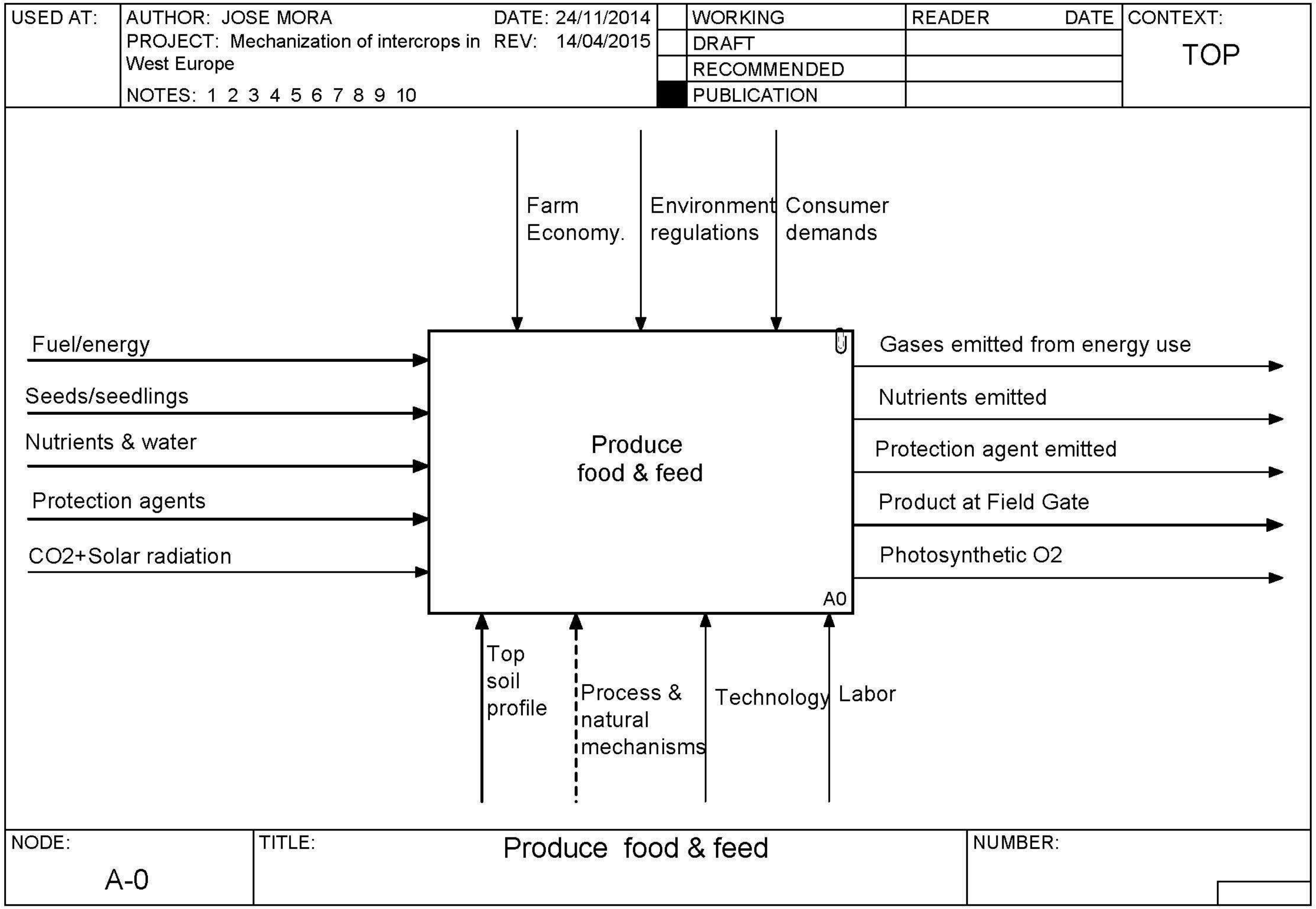
	Index	Objective	Requirement description	Variable/indicator	Min.value	Max.value	Target	Unit
Performance specification for subsystems	1	Cost of inputs Nitrate concentration N2O volatilization	Application of nutrients should match demands in terms of time and quantity of crop A and B, independently.	Agronomic nitrogen use efficiency for each crop's growing period	0.4	0.7	0.7	Kg uptaked/Kg applied
	2	Yield (crop A+B)	Application of nutrients to crop A should diminish neither yield nor quality of crop B, and vice versa.	Reduction in yield by phytotoxicity of nutrient spillover	0	3	0	% as compared to sole crops
	3	Yield (crop A+B)	Application of crop protection agent to crop A should diminish neither yield nor quality of crop B, and vice versa	Reduction in yield by phytotoxicity of herbicide's spillover	0	3	0	% as compared to sole crops
	4	Pesticides residues	Application of crop protection agents for crop A should not deposit on product of crop B, and vice versa	Increment on residue levels in product of the neighbor crop, as compared to the maximum residue level of it.	0	2	0	%
	5	Pesticides	Crop protection agents emission to	Reduction of measured	0	25	25	% as compared to

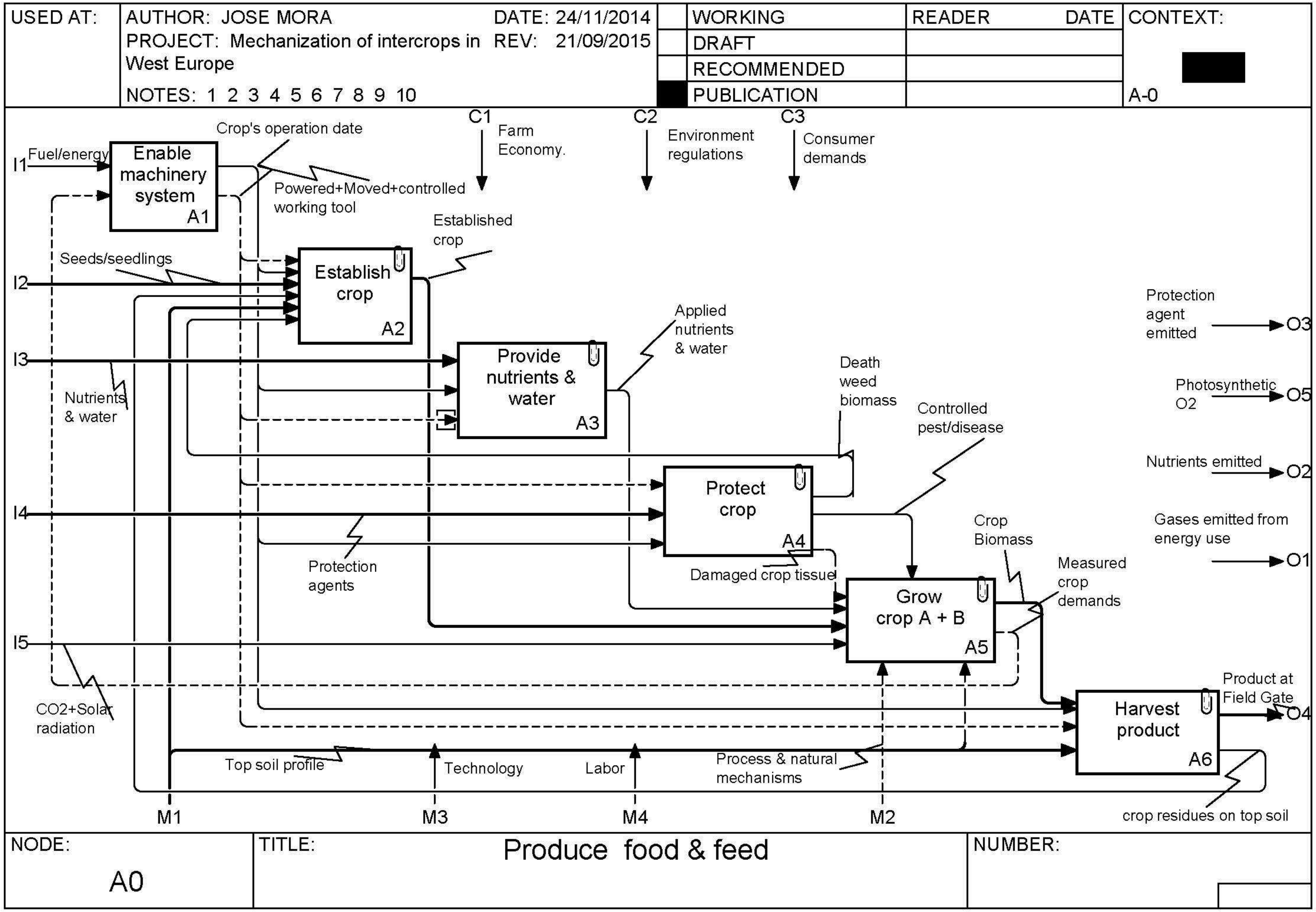
		concentration on environment	the environment should be reduced compared to sole crops	emissions				sole crops
	6	Yield (crop A+B)	Water should be accessible to crop A and B according to its respective evapotranspiration.	Irrigation use efficiency of each crops	70	90	90	Kg uptaked/kg applied
	7	Timeliness costs	Time for harvest operation per kg of harvested product should be equal compared to sole crops	Variation of total operational time/kg of harvested product, as compared to sole crops	0	5	0	%

Constraints across all subsystems	8	Cost of investment	Machinery should be able to operate in strips of 3 meter width	-	-	-	-	Qualitative
	9	Labor demand	Units labor per unit of harvested product should not be significantly greater than sole crops	Increment of unit of labor per unit of harvested product as compared to sole crops	0	5	0	%
	10	Yield (crop A+B) Soil compaction	Combined weight of machinery + inputs/outputs should not reduce yields of intercrops	Yield reduction by short term soil compaction	0	5	0	%
	11	Cost of investment	The return on investment should be equal or higher as compared to sole crops	Increment of ROI as compared to corresponding sole crops	0	5	5	%
	12	Soil Compaction	Combine weight of machinery + inputs/outputs should not produce soil compaction in the long term	Increment of sub-soil compaction as compared to undisturbed soils	0	5	0	%
	13	Soil organic	Soil organic matter levels should be	Organic matter content	3	8	8	%

	matter	maintain according soil type	(soil type dependent)				
14	CO2 emissions	CO2 foot print on products should be equal or lower than sole crops	Reduction in direct emissions of CO2 per unit of harvested product	0	20	20	%
15	Undesired crop injuries	Machinery operation of crop A should not harm the canopy of crop B, and vice versa	Photosynthesis reduction of neighbor crop	0	1	0	%
16	Undesired crop injuries	Machinery operation of crop A should not harm the roots of crop B, and vice versa	Damage of roots neighbor crop	0	1	0	%
17	Yield (crop A+B)	Machinery should be able to operate in scenarios of strip width of 1 meter.	-	-	-	-	-

Appendix 2: IDEF0 models for Generic arable crop system

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REV: 21/09/2015
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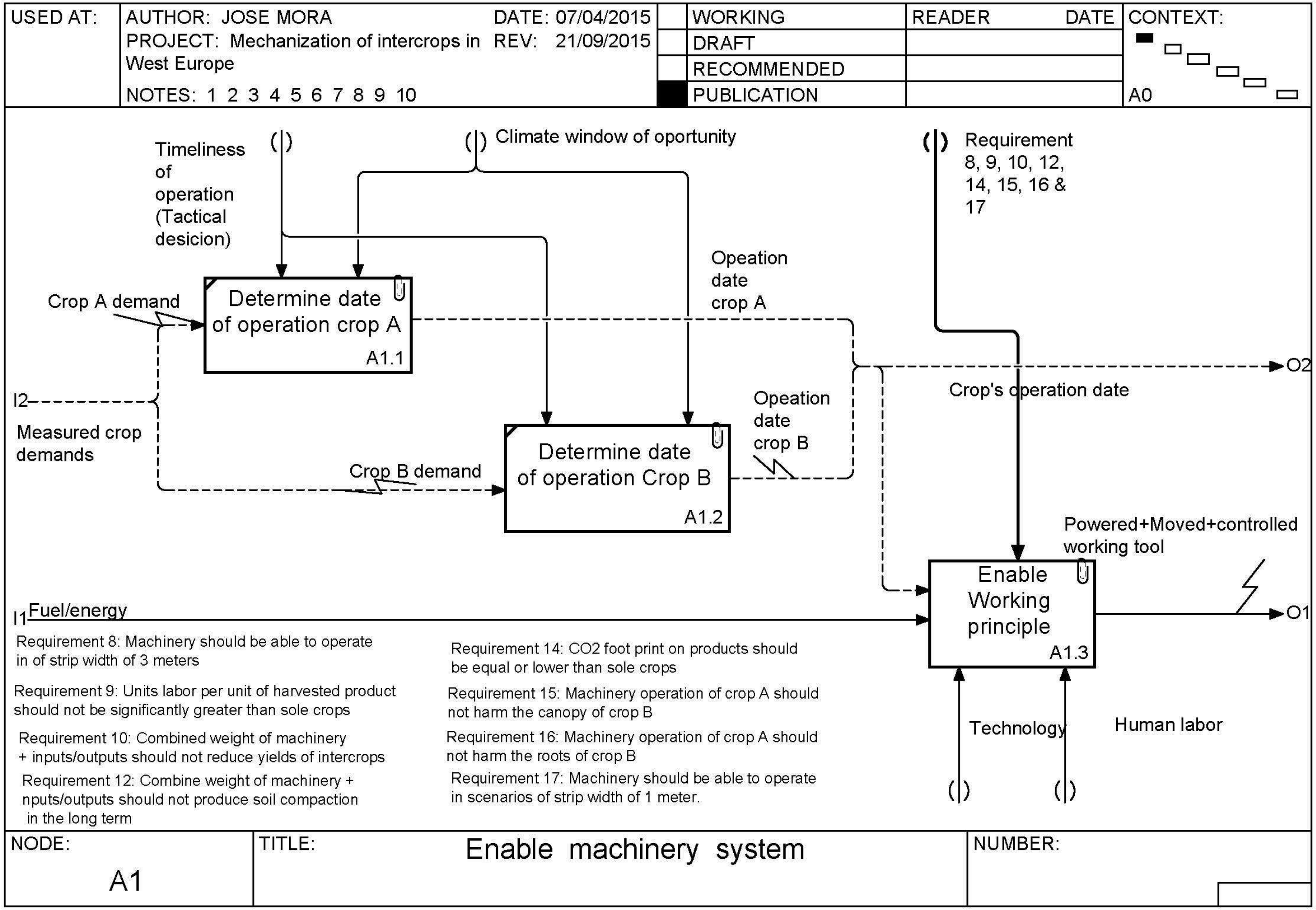
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A-0
C1
Farm Economy.
C2
Environment regulations
C3
Consumer demands
Crop's operation date
I1
Fuel/energy
Enable machinery system
A1
Powered+Moved+controlled working tool
Established crop
Seeds/seedlings
I2
Establish crop
A2
Applied nutrients & water
I3
Provide nutrients & water
A3
Nutrients & water
Death weed biomass
Controlled pest/disease
Protect crop
A4
I4
Protection agents
Damaged crop tissue
Crop Biomass
Measured crop demands
Grow crop A + B
A5
I5
CO2+Solar radiation
Harvest product
A6
Product at Field Gate
O4
Top soil profile
Technology
Labor
Process & natural mechanisms
crop residues on top soil
M1
M3
M4
M2
Protection agent emitted
O3
Photosynthetic O2
O5
Nutrients emitted
O2
Gases emitted from energy use
O1
NODE:
A0
TITLE:
Produce food & feed
NUMBER: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REV: 21/09/2015
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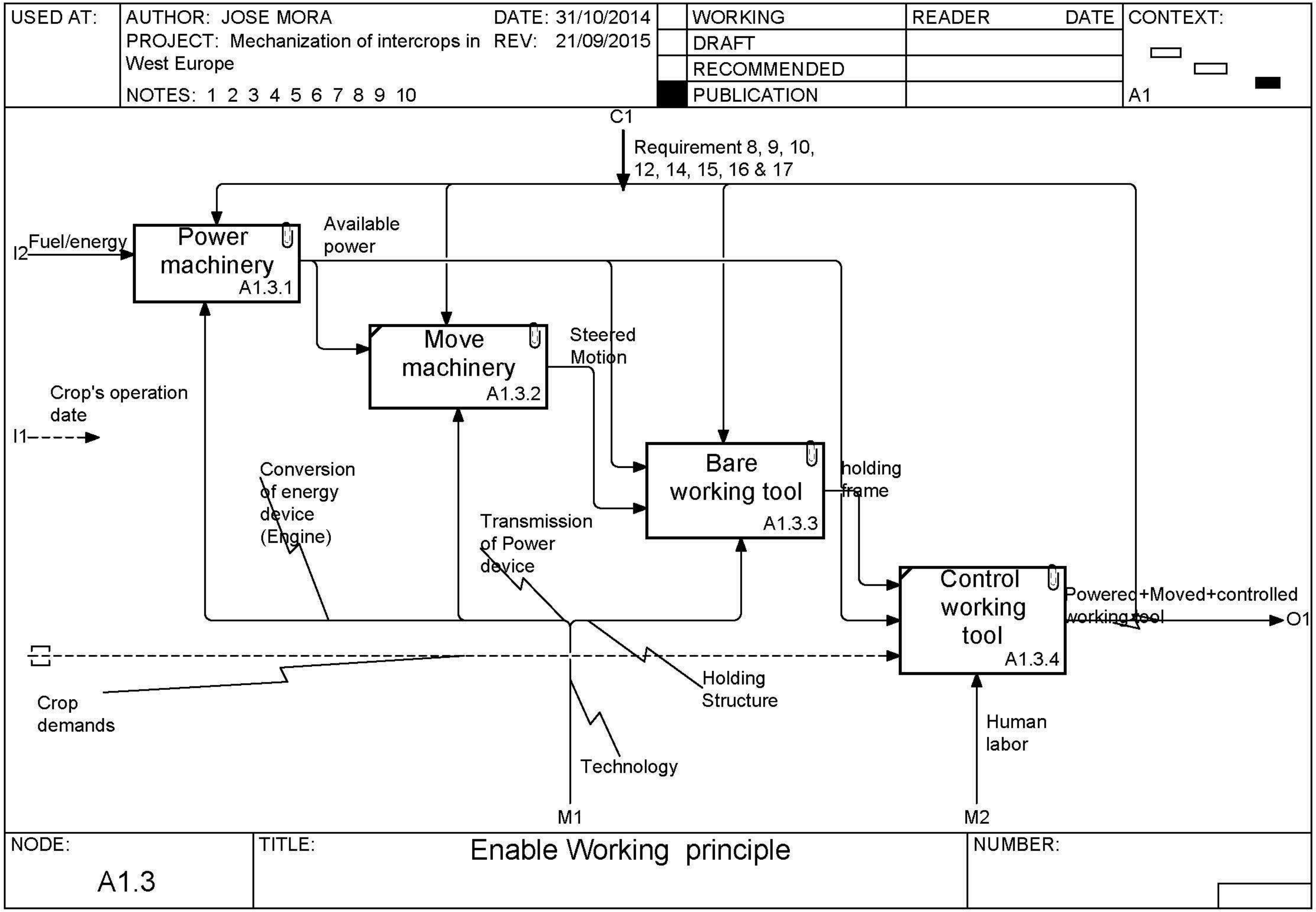
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A0
Timeliness of operation (Tactical desicion)
Climate window of oportunity
Requirement 8, 9, 10, 12, 14, 15, 16 & 17
Crop A demand
Determine date of operation crop A
A1.1
Opeation date crop A
O2
Crop's operation date
I2
Measured crop demands
Determine date of operation Crop B
A1.2
Opeation date crop B
Crop B demand
Powered+Moved+controlled working tool
Enable Working principle
A1.3
O1
I1
Fuel/energy
Requirement 8: Machinery should be able to operate in of strip width of 3 meters
Requirement 9: Units labor per unit of harvested product should not be significantly greater than sole crops
Requirement 10: Combined weight of machinery + inputs/outputs should not reduce yields of intercrops
Requirement 12: Combine weight of machinery + nputs/outputs should not produce soil compaction in the long term
Requirement 14: CO2 foot print on products should be equal or lower than sole crops
Requirement 15: Machinery operation of crop A should not harm the canopy of crop B
Requirement 16: Machinery operation of crop A should not harm the roots of crop B
Requirement 17: Machinery should be able to operate in scenarios of strip width of 1 meter.
Technology
Human labor
NODE:
A1
TITLE:
Enable machinery system
NUMBER: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DATE: 31/10/2014
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REV: 21/09/2015
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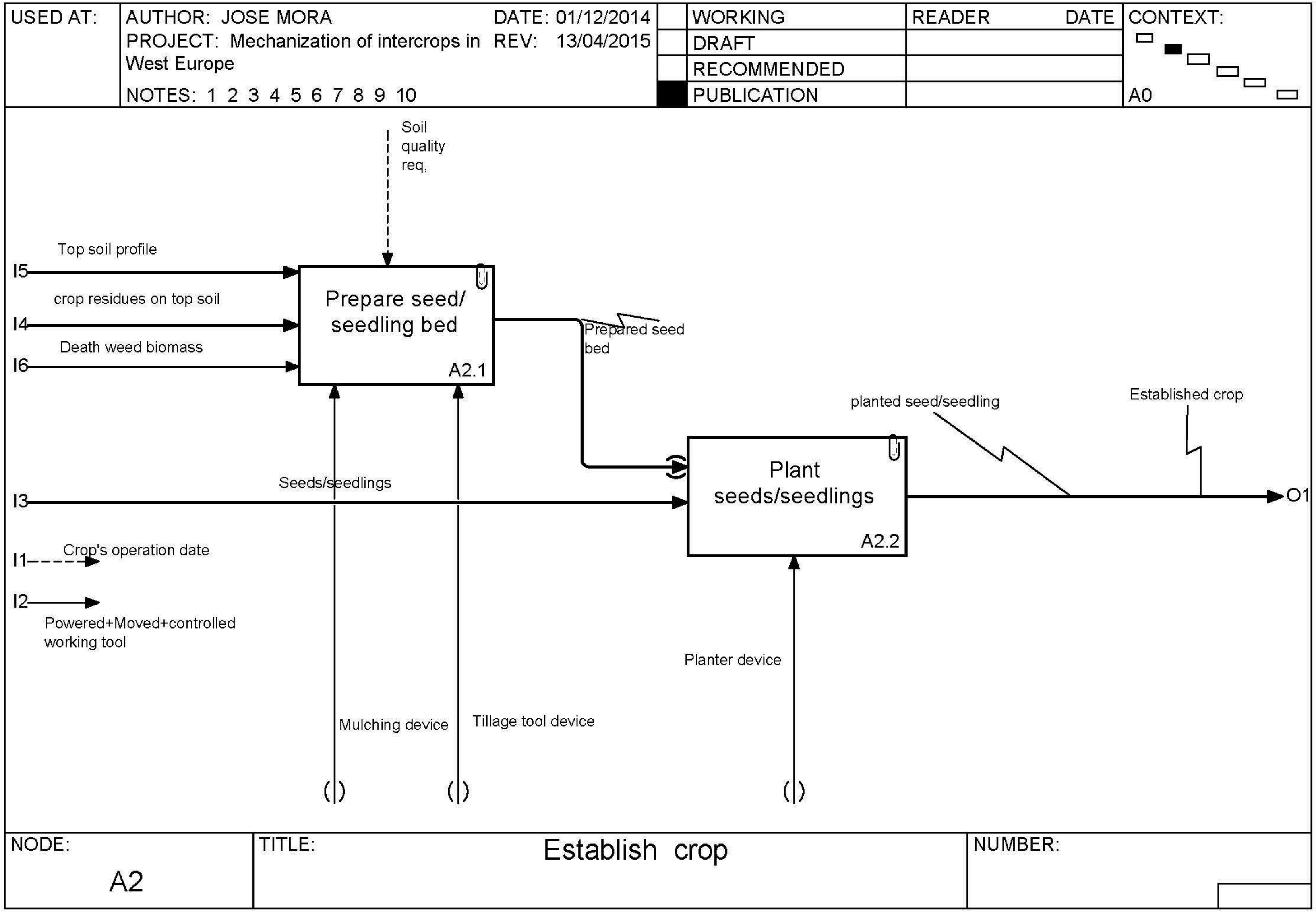
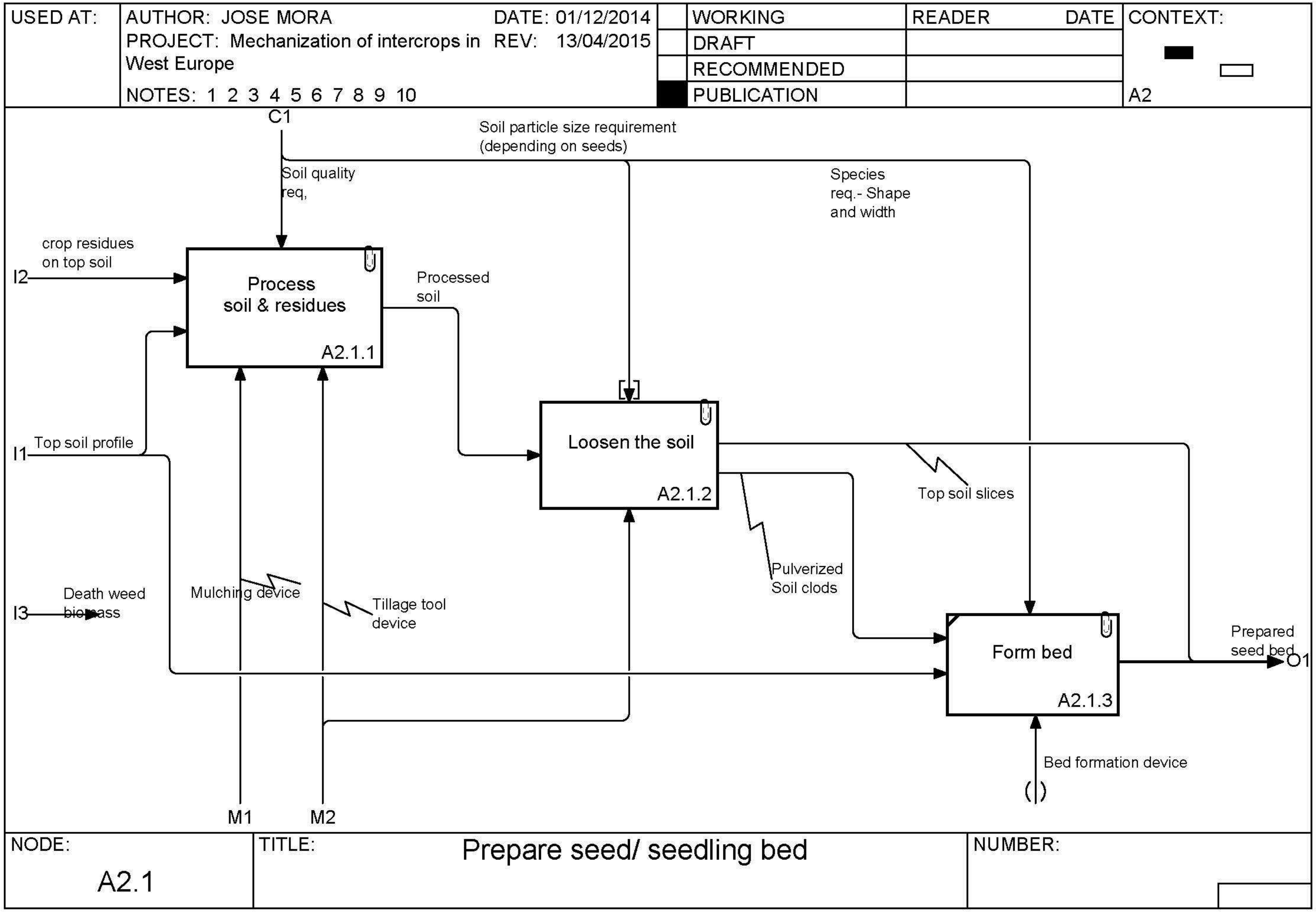
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A1
C1
Requirement 8, 9, 10, 12, 14, 15, 16 & 17
I2
Fuel/energy
Power machinery
A1.3.1
Available power
Move machinery
A1.3.2
Steered Motion
Crop's operation date
I1
Bare working tool
A1.3.3
holding frame
Conversion of energy device (Engine)
Transmission of Power device
Control working tool
A1.3.4
Powered+Moved+controlled working tool
O1
Holding Structure
Crop demands
Technology
Human labor
M1
M2
NODE:
A1.3
TITLE:
Enable Working principle
NUMBER:

AppendixApendix

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REV: 13/04/2015
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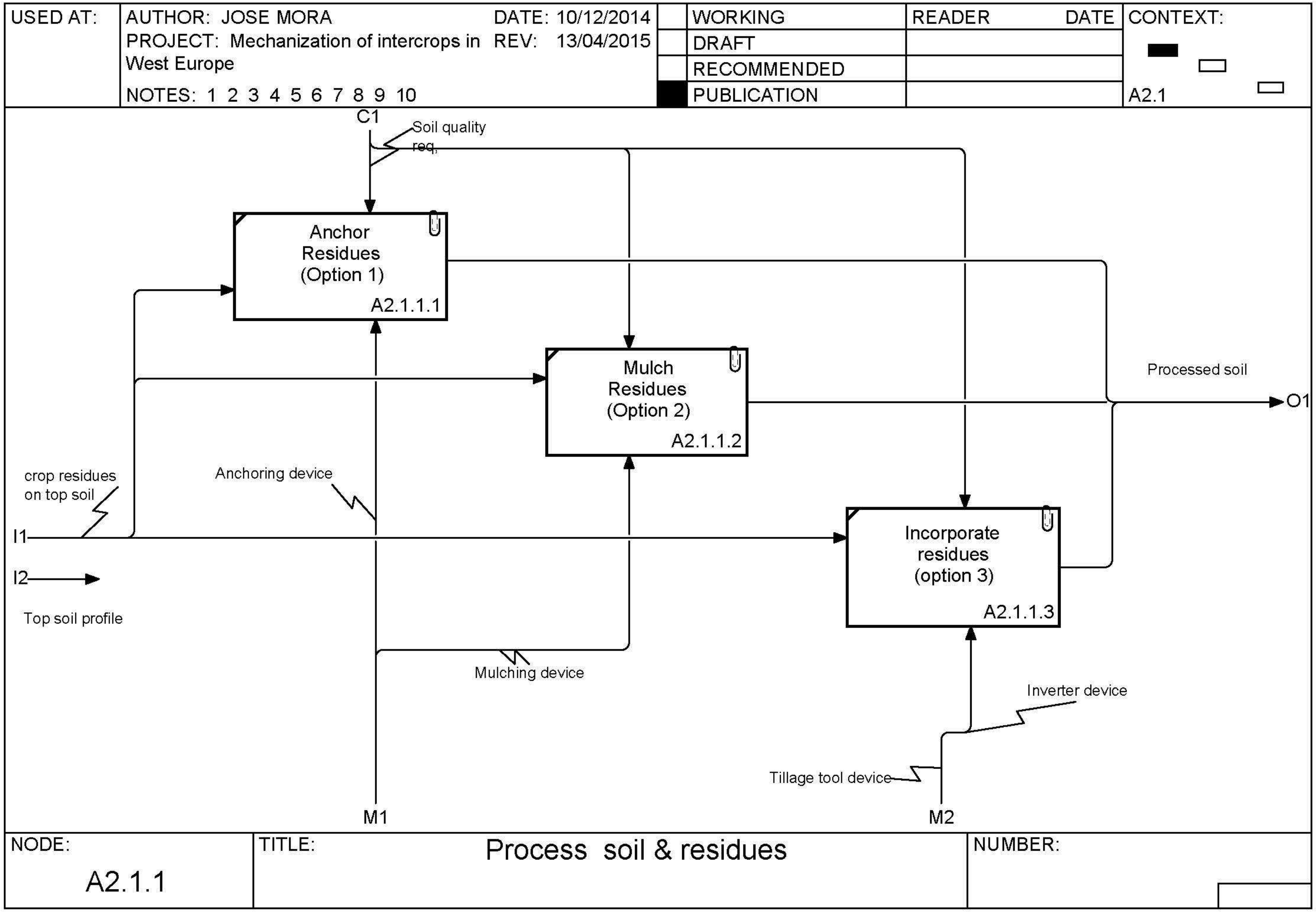
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A2
C1
Soil particle size requirement (depending on seeds)
Soil quality req,
Species req.- Shape and width
crop residues on top soil
I2
Process soil & residues
A2.1.1
Processed soil
Loosen the soil
A2.1.2
I1
Top soil profile
Top soil slices
Pulverized Soil clods
I3
Death weed biomass
Mulching device
Tillage tool device
Form bed
A2.1.3
Prepared seed bed
O1
Bed formation device
M1
M2
NODE:
A2.1
TITLE:
Prepare seed/ seedling bed
NUMBER: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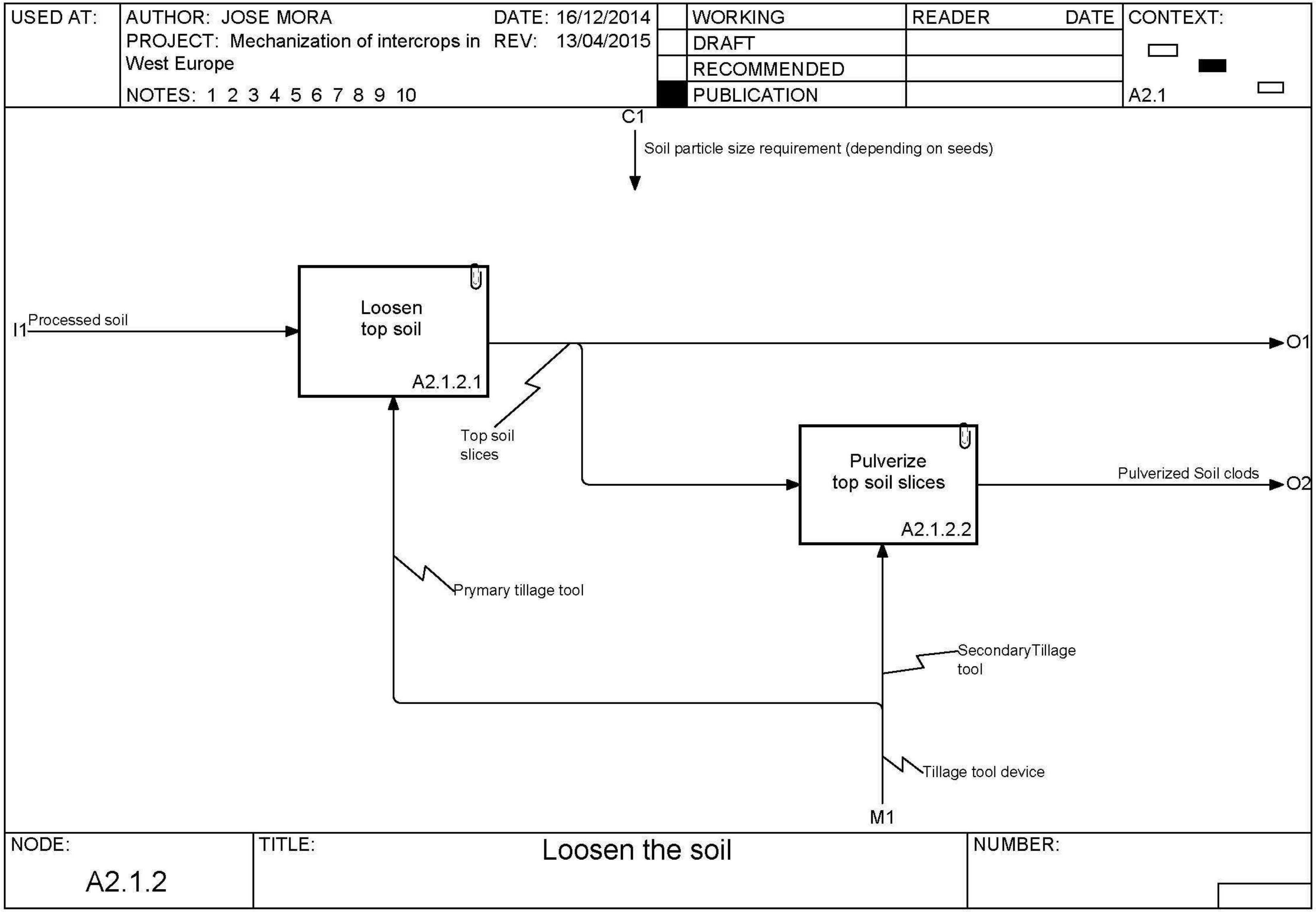
DATE: 10/12/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 13/04/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A2.1
C1
Soil quality req.
Anchor Residues (Option 1)
A2.1.1.1
Mulch Residues (Option 2)
A2.1.1.2
Incorporate residues (option 3)
A2.1.1.3
Processed soil
O1
crop residues on top soil
I1
I2
Top soil profile
Anchoring device
Mulching device
Inverter device
Tillage tool device
M1
M2
NODE:
A2.1.1
TITLE:
Process soil & residues
NUMBER: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DATE: 16/12/2014
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REV: 13/04/2015
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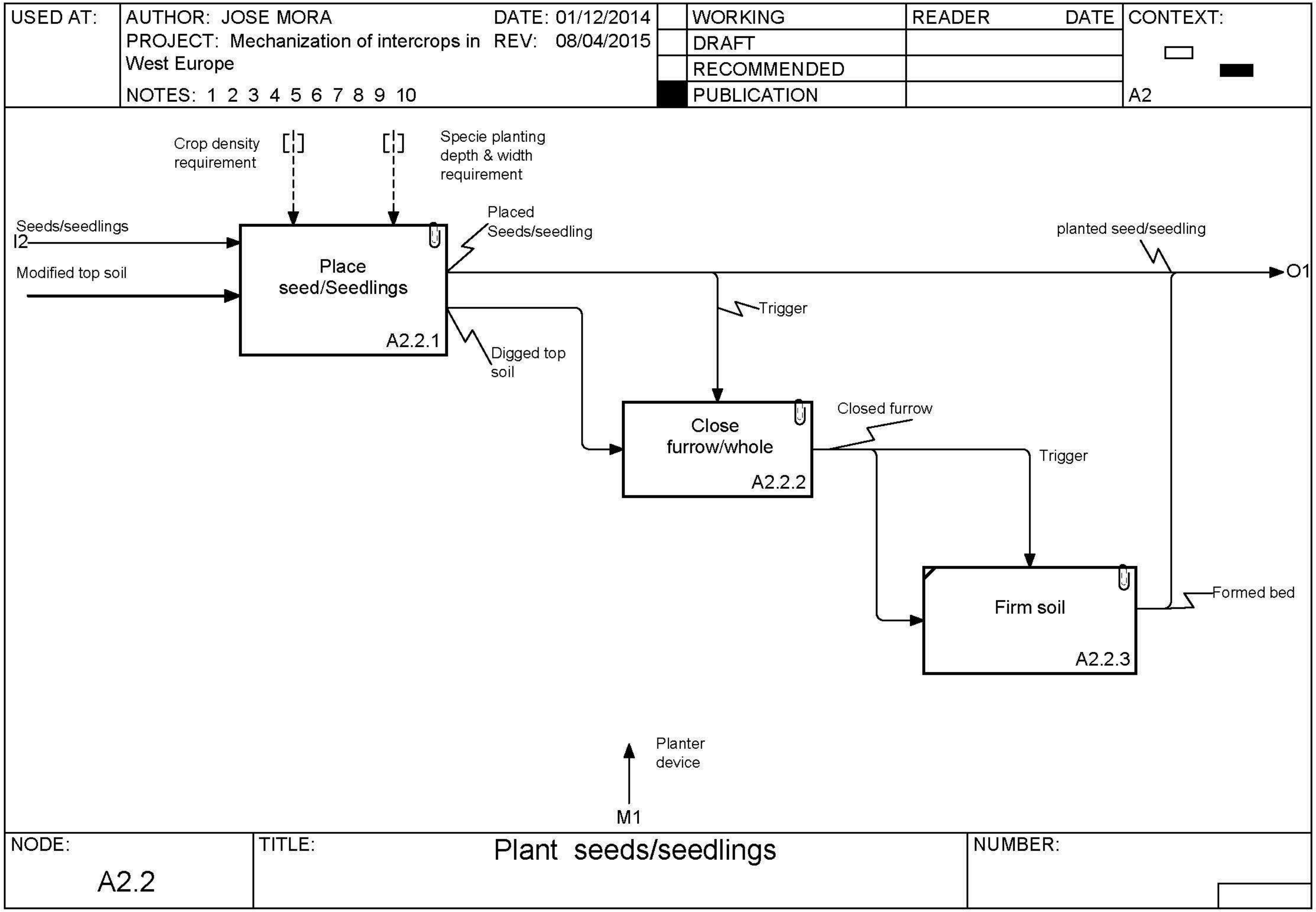
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A2.1
C1
Soil particle size requirement (depending on seeds)
I1
Processed soil
Loosen
top soil
A2.1.2.1
O1
Top soil
slices
Pulverize
top soil slices
A2.1.2.2
Pulverized Soil clods
O2
Prymary tillage tool
SecondaryTillage
tool
Tillage tool device
M1
NODE:
A2.1.2
TITLE:
Loosen the soil
NUMBER: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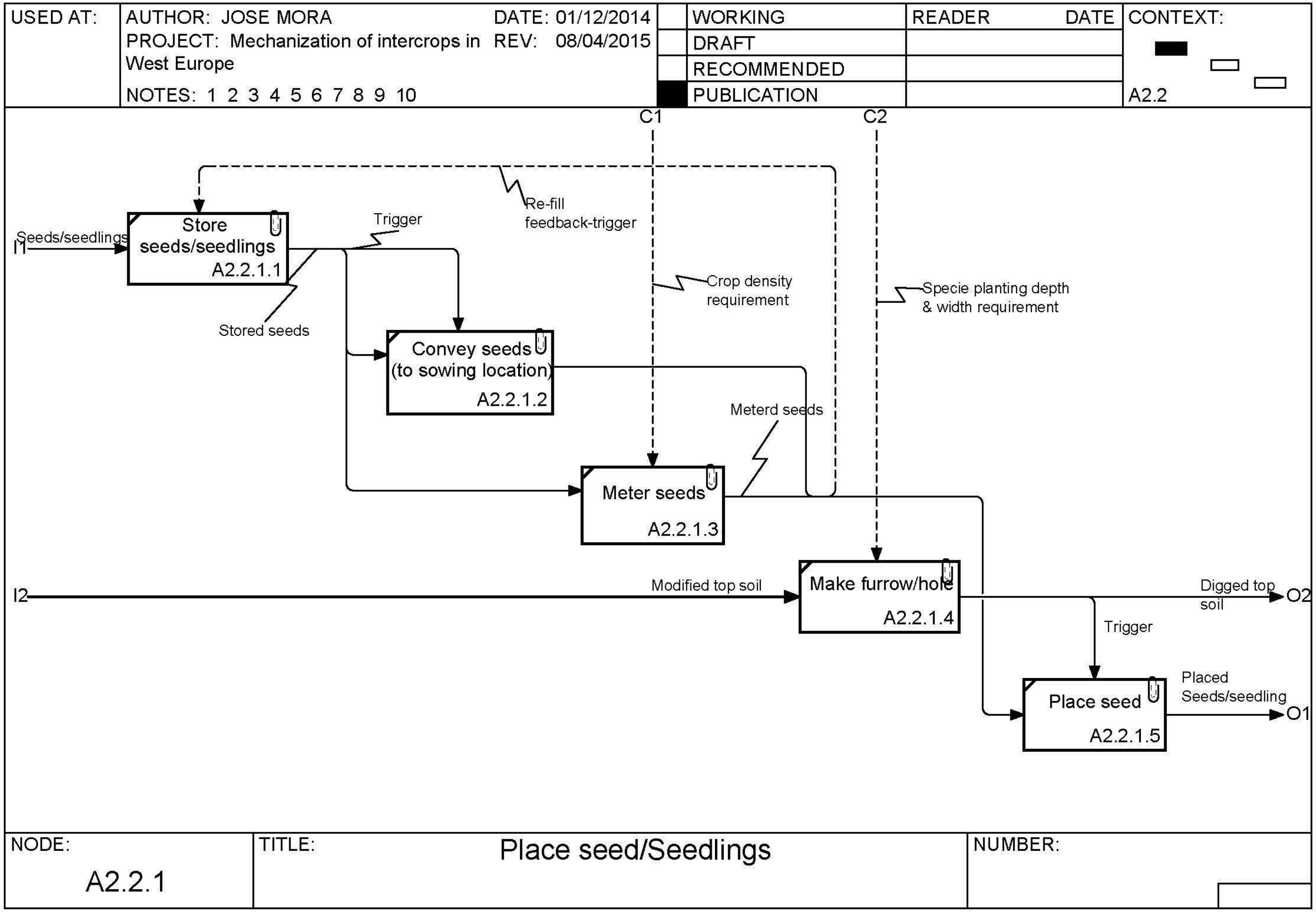
DATE: 01/12/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 08/04/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A2
Crop density requirement
Specie planting depth & width requirement
Seeds/seedlings
I2
Modified top soil
Place seed/Seedlings
A2.2.1
Placed Seeds/seedling
planted seed/seedling
O1
Trigger
Digged top soil
Close furrow/whole
A2.2.2
Closed furrow
Trigger
Firm soil
A2.2.3
Formed bed
Planter device
M1
NODE:
A2.2
TITLE:
Plant seeds/seedlings
NUMBER: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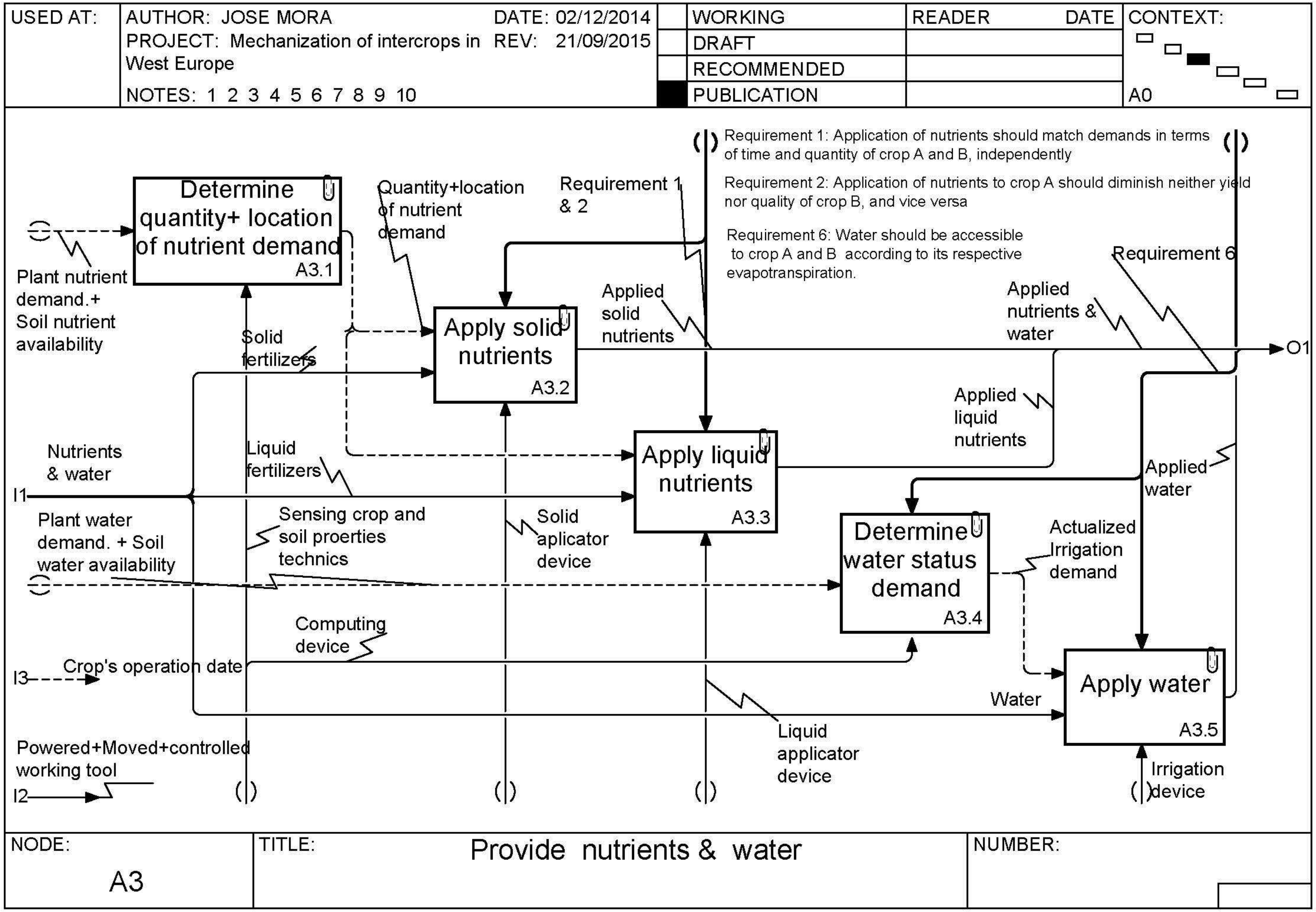
DATE: 01/12/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 08/04/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A2.2
C1
C2
Re-fill feedback-trigger
Seeds/seedlings
I1
Store seeds/seedlings
A2.2.1.1
Trigger
Stored seeds
Crop density requirement
Specie planting depth & width requirement
Convey seeds (to sowing location)
A2.2.1.2
Meterd seeds
Meter seeds
A2.2.1.3
I2
Modified top soil
Make furrow/hole
A2.2.1.4
Digged top soil
O2
Trigger
Placed Seeds/seedling
O1
Place seed
A2.2.1.5
NODE:
A2.2.1
TITLE:
Place seed/Seedlings
NUMBER: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DATE: 02/12/2014
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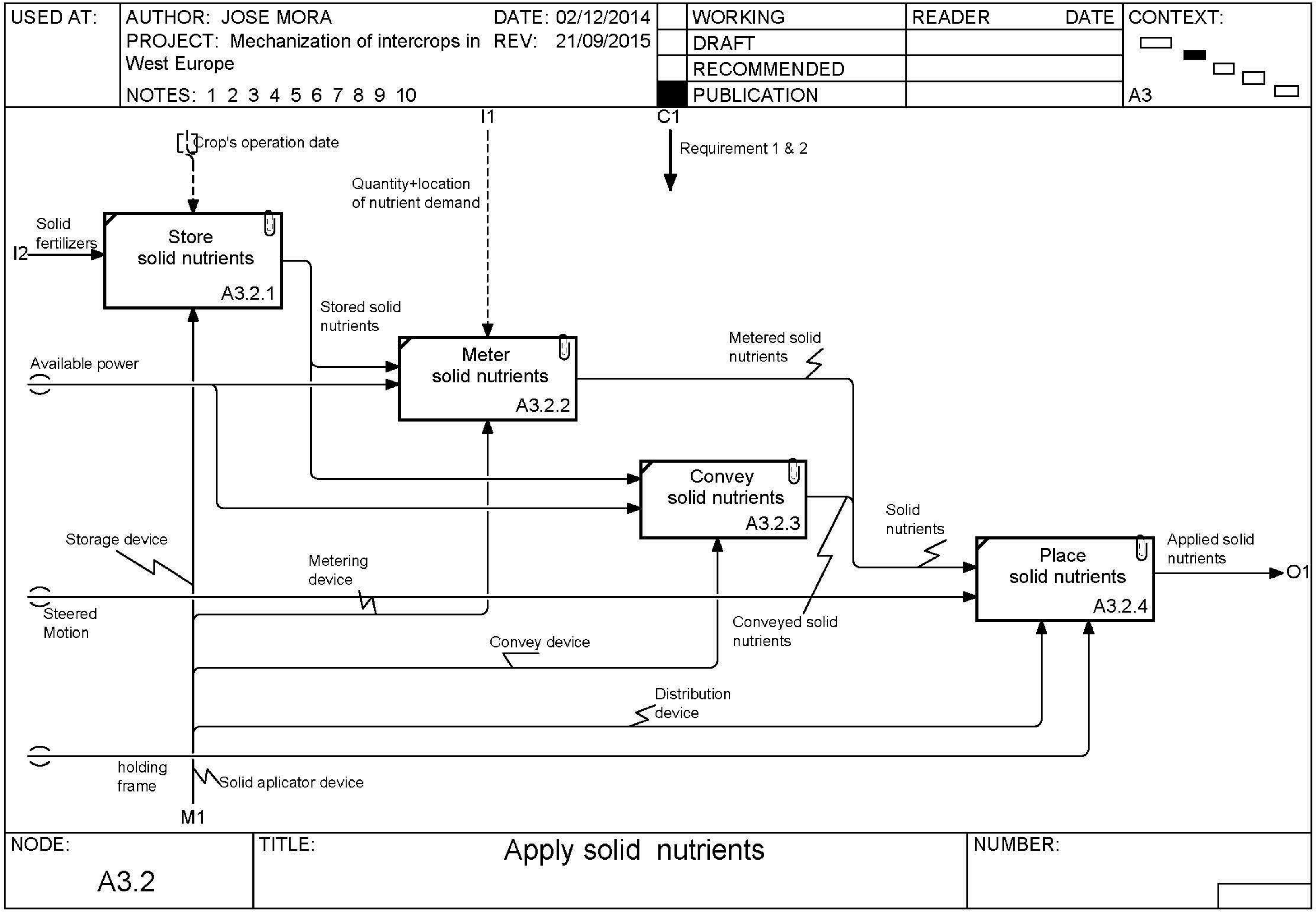
REV: 21/09/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A0
Requirement 1: Application of nutrients should match demands in terms of time and quantity of crop A and B, independently
Requirement 2: Application of nutrients to crop A should diminish neither yield nor quality of crop B, and vice versa
Requirement 6: Water should be accessible to crop A and B according to its respective evapotranspiration.
Determine quantity+ location of nutrient demand
A3.1
Plant nutrient demand.+ Soil nutrient availability
Quantity+location of nutrient demand
Requirement 1 & 2
Apply solid nutrients
A3.2
Applied solid nutrients
Solid fertilizers
Requirement 6
Applied nutrients & water
O1
Applied liquid nutrients
Nutrients & water
I1
Liquid fertilizers
Apply liquid nutrients
A3.3
Applied water
Plant water demand. + Soil water availability
Sensing crop and soil proerties technics
Solid aplicator device
Determine water status demand
A3.4
Actualized Irrigation demand
Computing device
I3
Crop's operation date
Apply water
A3.5
Water
Liquid applicator device
Powered+Moved+controlled working tool
I2
Irrigation device
NODE:
A3
TITLE:
Provide nutrients & water
NUMBER: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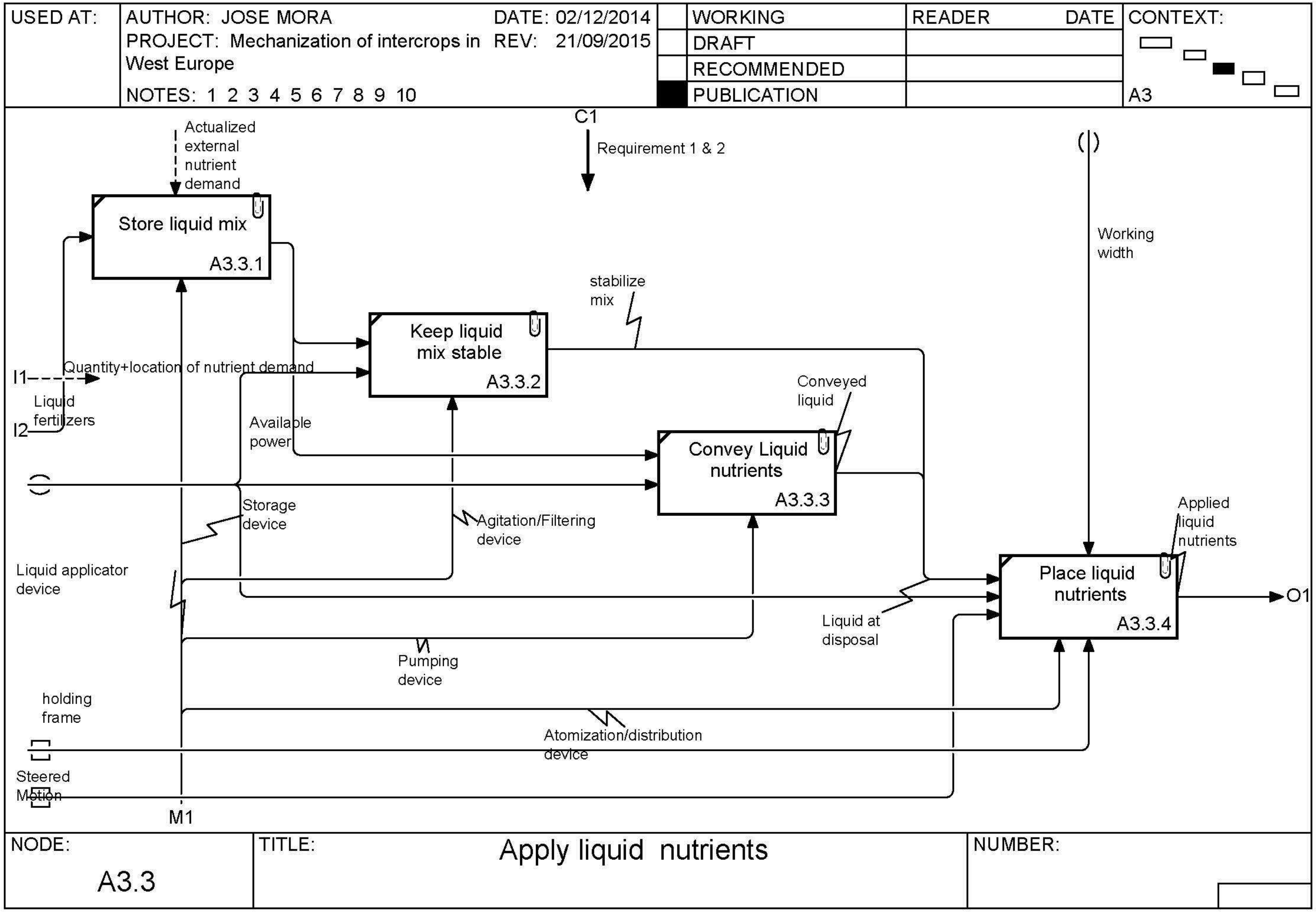
REV: 21/09/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A3
I1
C1
Crop's operation date
Requirement 1 & 2
Quantity+location of nutrient demand
Solid fertilizers
I2
Store solid nutrients
A3.2.1
Stored solid nutrients
Meter solid nutrients
A3.2.2
Metered solid nutrients
Available power
Convey solid nutrients
A3.2.3
Solid nutrients
Place solid nutrients
A3.2.4
Applied solid nutrients
O1
Storage device
Metering device
Steered Motion
Conveyed solid nutrients
Convey device
Distribution device
holding frame
Solid aplicator device
M1
NODE:
A3.2
TITLE:
Apply solid nutrients
NUMBER: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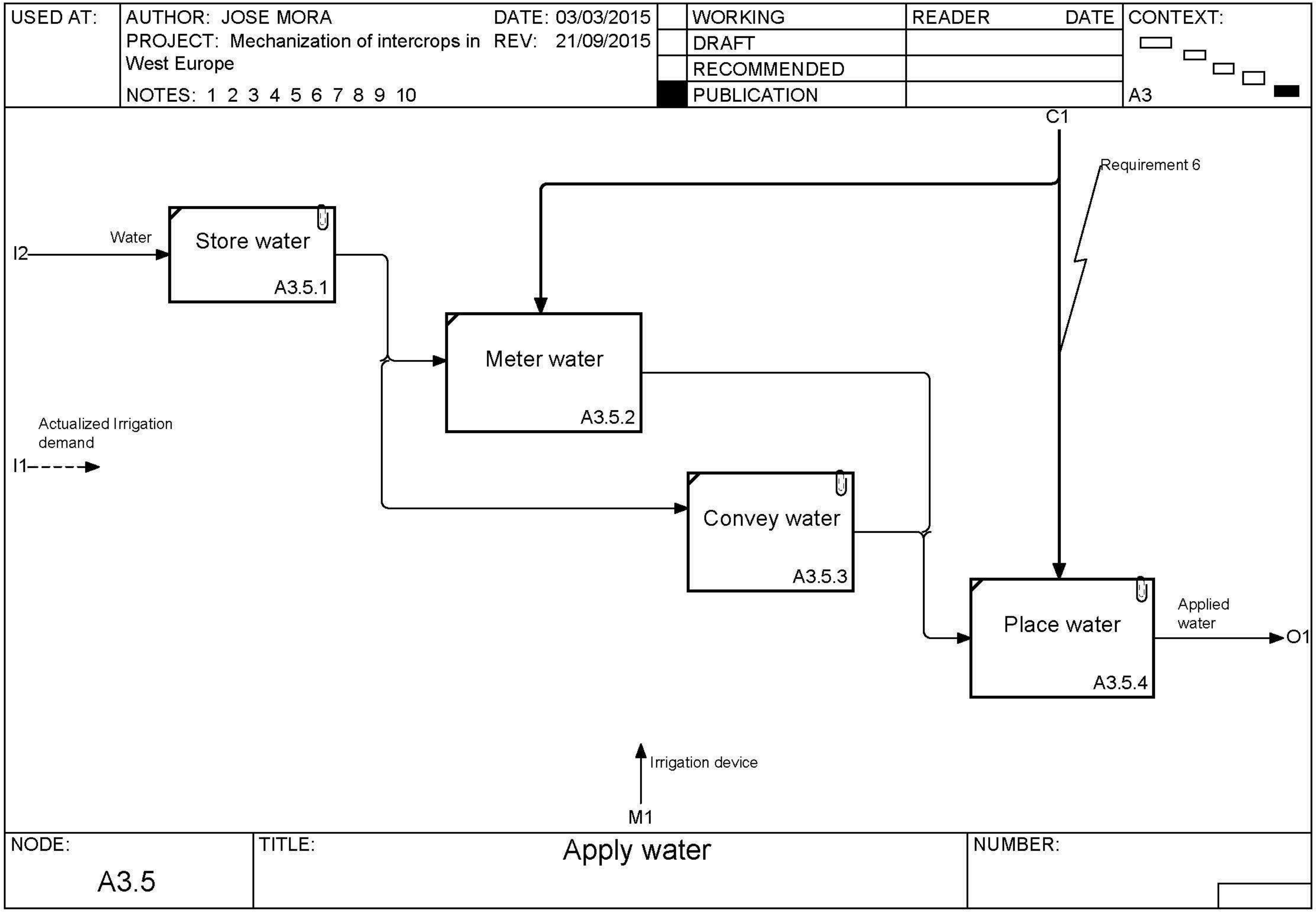
REV: 21/09/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A3
C1
Requirement 1 & 2
Actualized external nutrient demand
Store liquid mix
A3.3.1
Keep liquid mix stable
A3.3.2
stabilize mix
Working width
I1
Quantity+location of nutrient demand
Liquid fertilizers
I2
Available power
Conveyed liquid
Convey Liquid nutrients
A3.3.3
Storage device
Agitation/Filtering device
Applied liquid nutrients
Liquid applicator device
Place liquid nutrients
A3.3.4
O1
Liquid at disposal
Pumping device
holding frame
Atomization/distribution device
Steered Motion
M1
NODE:
A3.3
TITLE:
Apply liquid nutrients
NUMBER: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DATE: 03/03/2015
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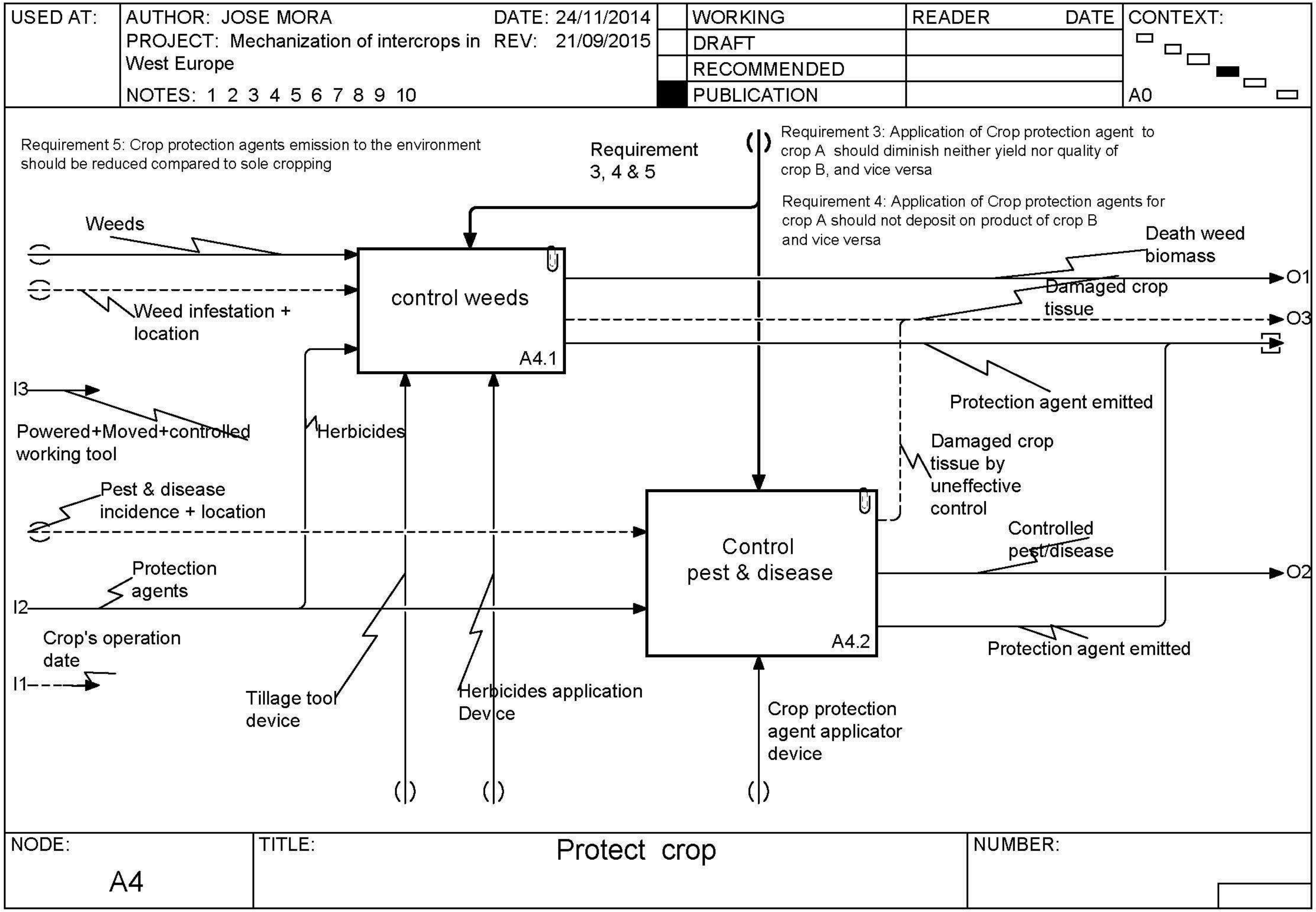
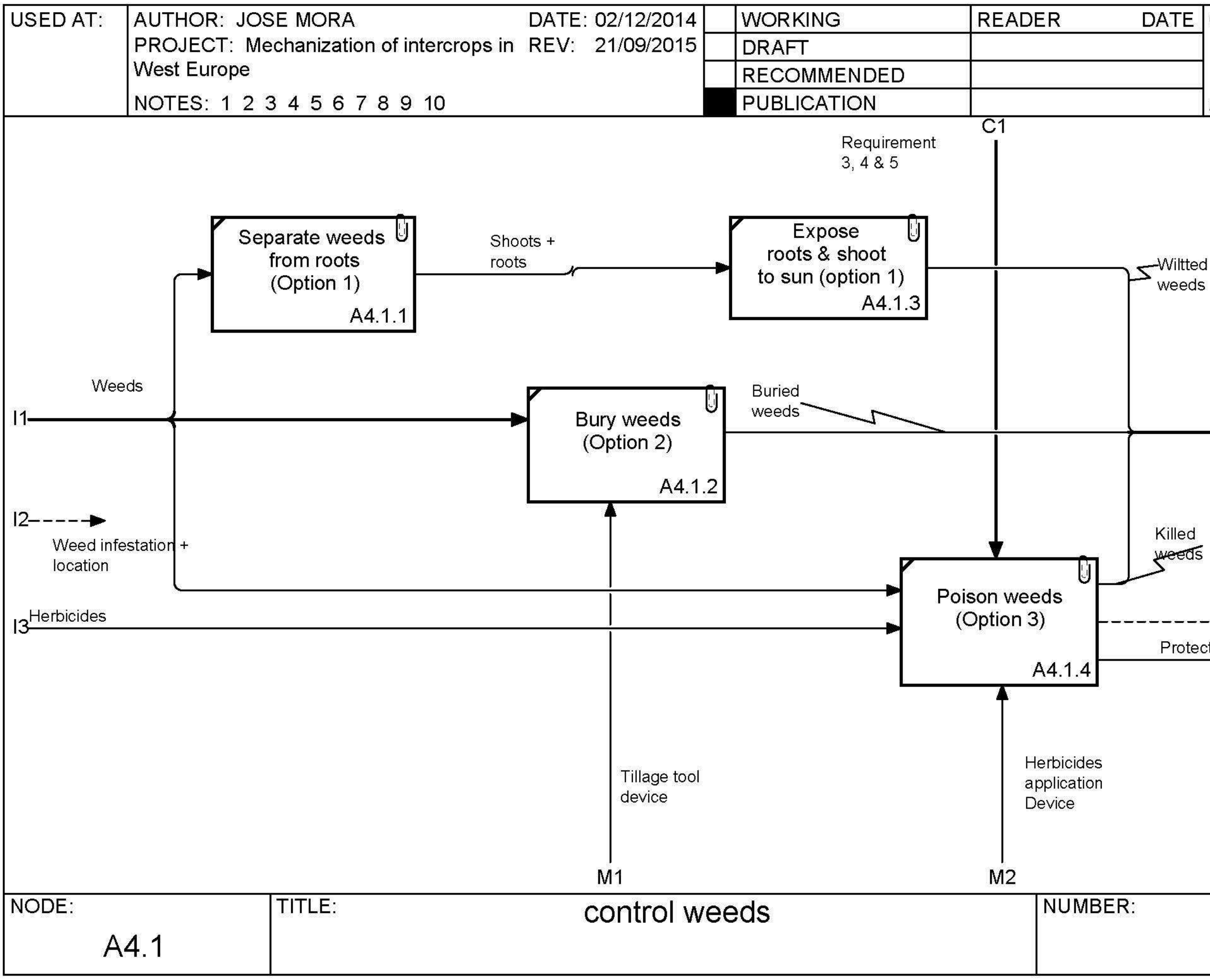
REV: 21/09/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A3
C1
Requirement 6
I2
Water
Store water
A3.5.1
Meter water
A3.5.2
Actualized Irrigation demand
I1
Convey water
A3.5.3
Place water
A3.5.4
Applied water
O1
Irrigation device
M1
NODE:
A3.5
TITLE:
Apply water
NUMBER:

AppendixApendix

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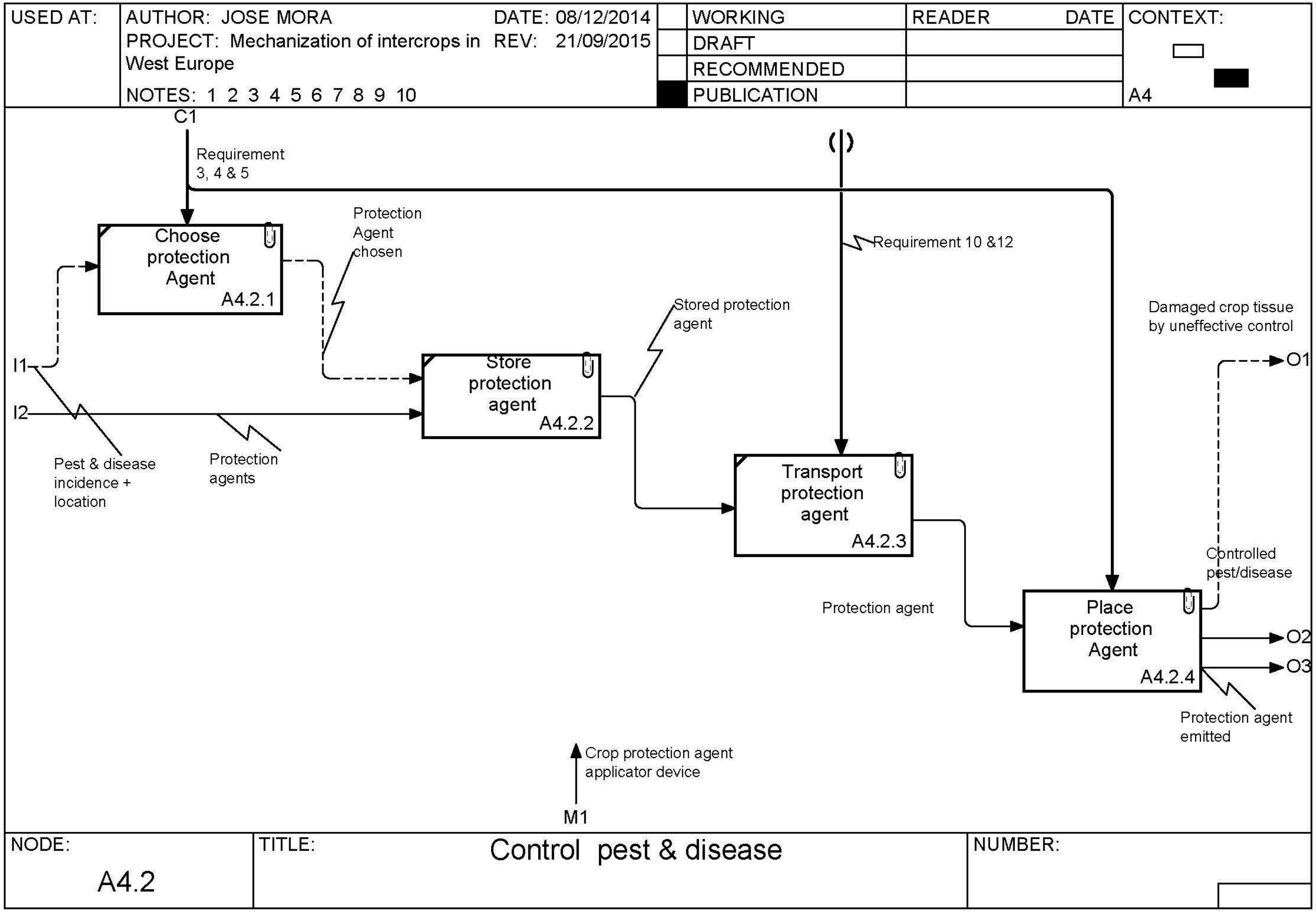
REV: 21/09/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
C1
Requirement 3, 4 & 5
Separate weeds from roots (Option 1)
A4.1.1
Shoots + roots
Expose roots & shoot to sun (option 1)
A4.1.3
Wiltted weeds
Weeds
I1
Bury weeds (Option 2)
A4.1.2
Buried weeds
I2
Weed infestation + location
Killed weeds
Poison weeds (Option 3)
A4.1.4
I3
Herbicides
Protec
Tillage tool device
Herbicides application Device
M1
M2
NODE:
A4.1
TITLE:
control weeds
NUMBER: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AUTHOR: JOSE MORA
DATE: 08/12/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 21/09/2015
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WORKING
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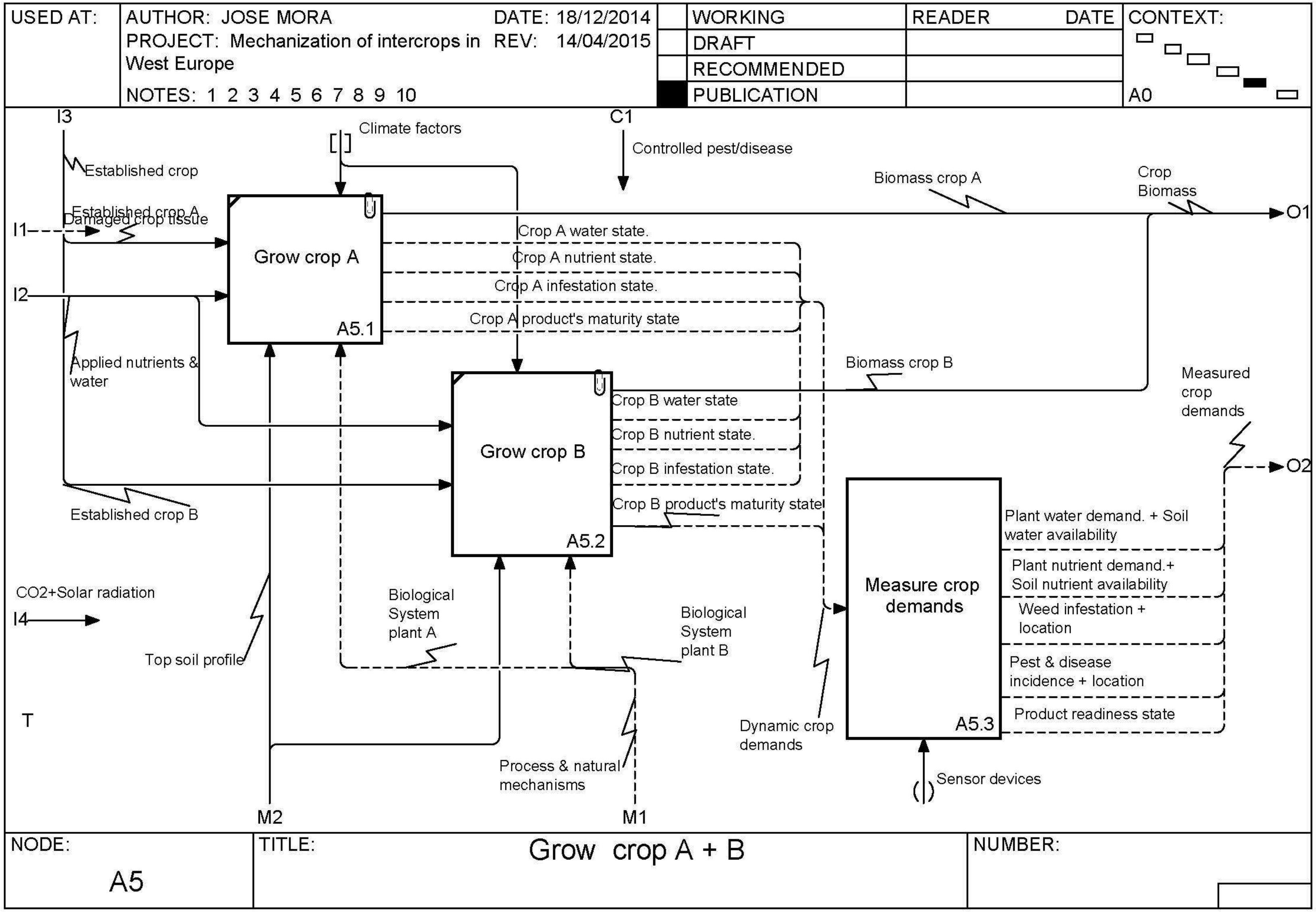
DATE
CONTEXT:
A4
C1
Requirement 3, 4 & 5
Choose protection Agent
A4.2.1
Protection Agent chosen
Store protection agent
A4.2.2
Stored protection agent
Requirement 10 &12
Transport protection agent
A4.2.3
Protection agent
Place protection Agent
A4.2.4
Damaged crop tissue by uneffective control
O1
Controlled pest/disease
O2
O3
Protection agent emitted
I1
I2
Pest & disease incidence + location
Protection agents
Crop protection agent applicator device
M1
NODE:
A4.2
TITLE:
Control pest & disease
NUMBER: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DATE: 18/12/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 14/04/2015
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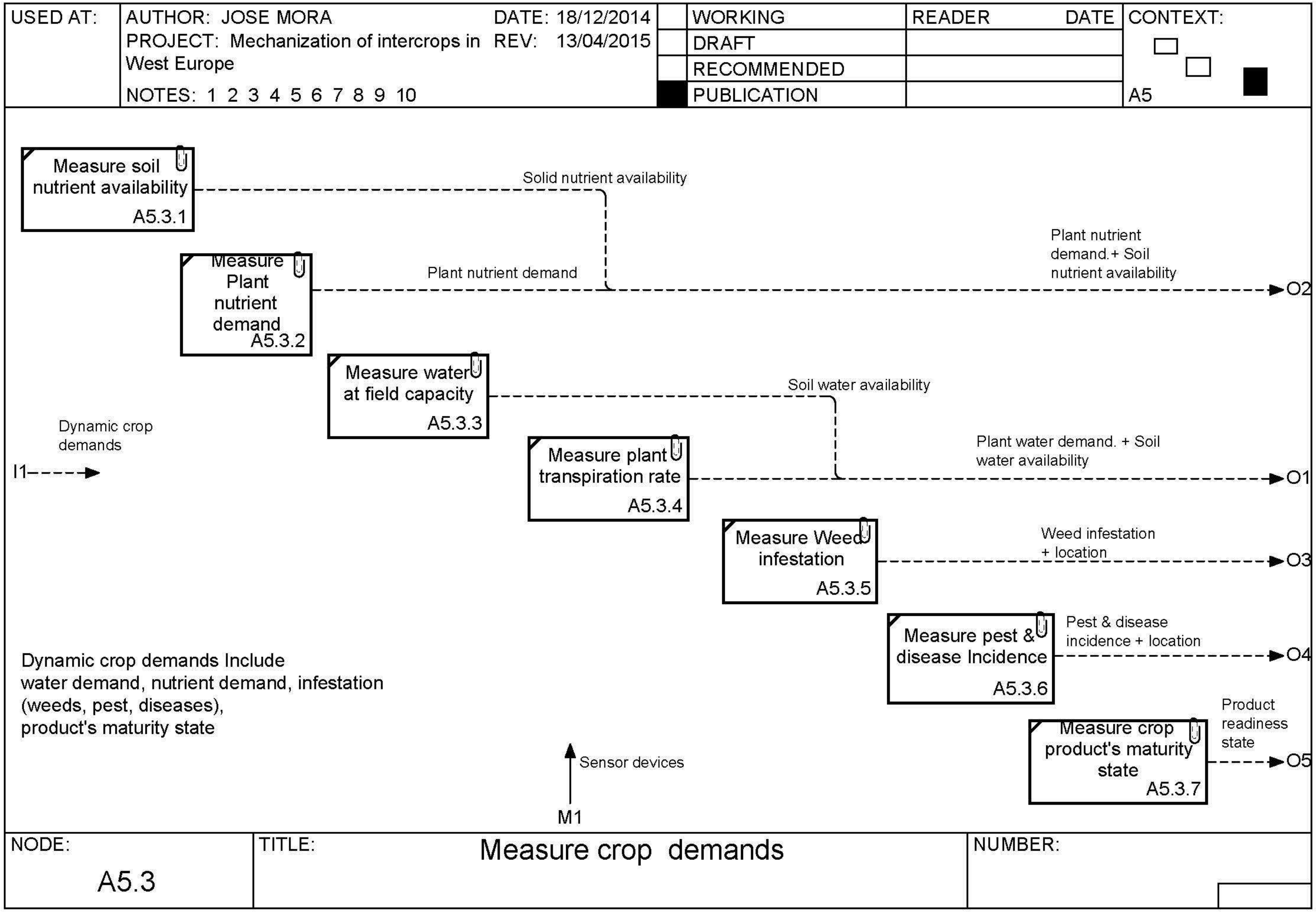
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A0
I3
Established crop
Climate factors
C1
Controlled pest/disease
Biomass crop A
Crop Biomass
O1
Established crop A
Damaged crop tissue
I1
I2
Grow crop A
A5.1
Crop A water state.
Crop A nutrient state.
Crop A infestation state.
Crop A product's maturity state
Applied nutrients & water
Biomass crop B
Measured crop demands
Grow crop B
A5.2
Crop B water state
Crop B nutrient state.
Crop B infestation state.
Crop B product's maturity state
O2
Established crop B
Measure crop demands
A5.3
Plant water demand. + Soil water availability
Plant nutrient demand.+ Soil nutrient availability
Weed infestation + location
Pest & disease incidence + location
Product readiness state
CO2+Solar radiation
I4
Biological System plant A
Biological System plant B
Top soil profile
Dynamic crop demands
T
Process & natural mechanisms
Sensor devices
M2
M1
NODE:
A5
TITLE:
Grow crop A + B
NUMBER: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DATE: 18/12/2014
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REV: 13/04/2015
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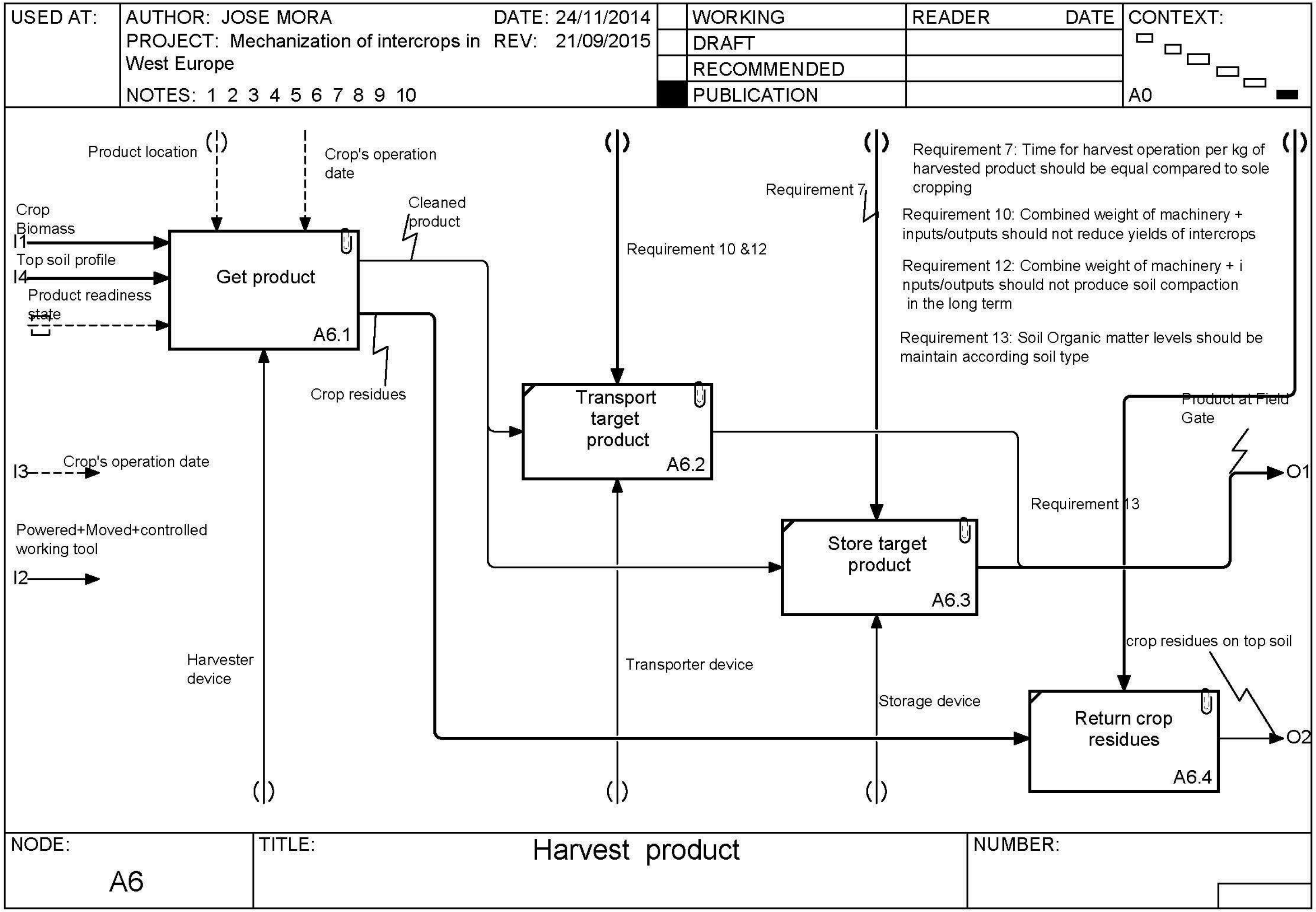
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A5
Measure soil nutrient availability A5.3.1
Solid nutrient availability
Measure Plant nutrient demand A5.3.2
Plant nutrient demand
Plant nutrient demand.+ Soil nutrient availability
O2
Measure water at field capacity A5.3.3
Soil water availability
Dynamic crop demands
I1
Measure plant transpiration rate A5.3.4
Plant water demand. + Soil water availability
O1
Measure Weed infestation A5.3.5
Weed infestation + location
O3
Measure pest & disease Incidence A5.3.6
Pest & disease incidence + location
O4
Dynamic crop demands Include water demand, nutrient demand, infestation (weeds, pest, diseases), product's maturity state
Measure crop product's maturity state A5.3.7
Product readiness state
O5
Sensor devices
M1
NODE:
A5.3
TITLE:
Measure crop demands
NUMBER: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DATE: 24/11/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 21/09/2015
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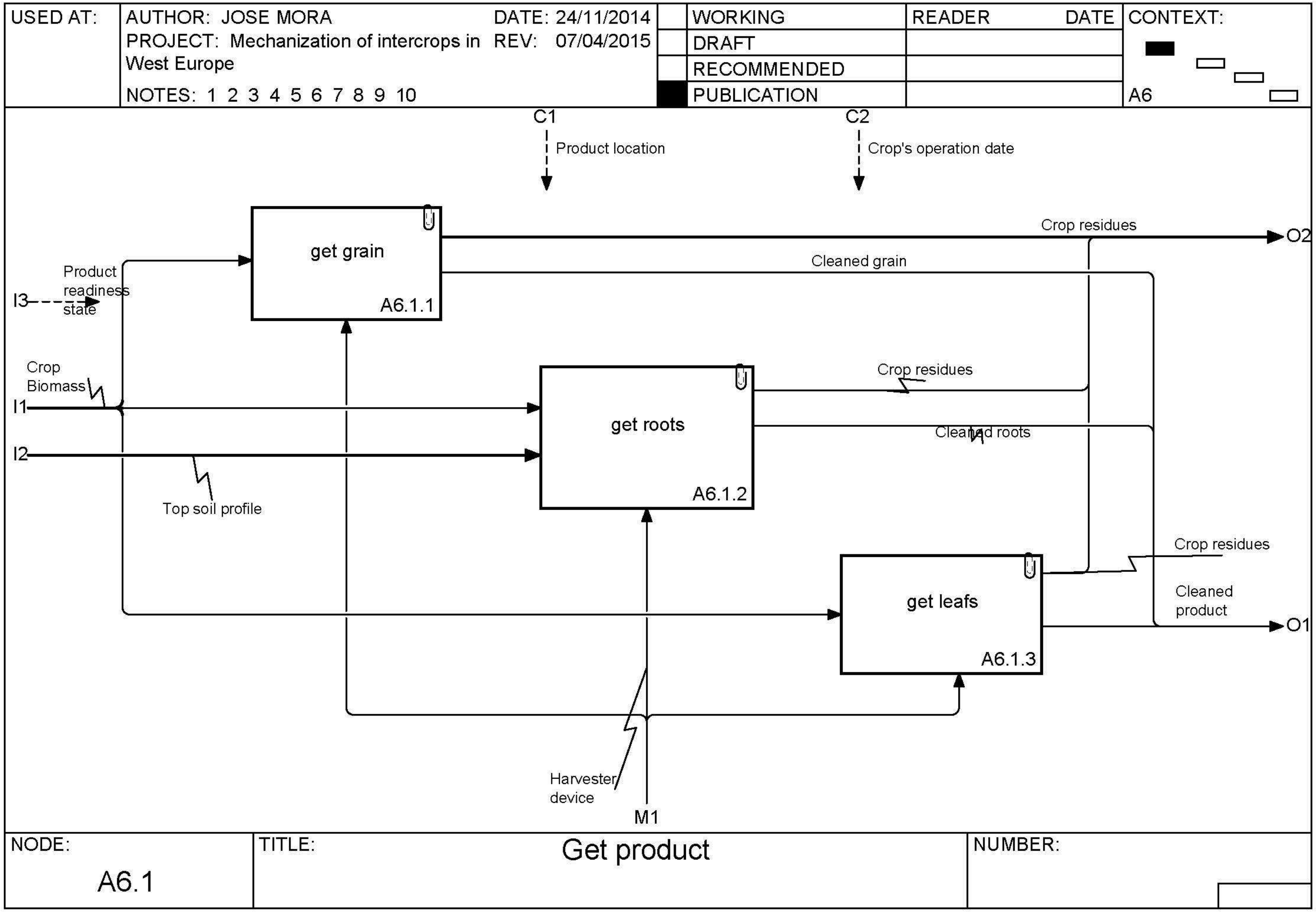
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A0
Product location
Crop's operation date
Crop Biomass
I1
Top soil profile
I4
Product readiness state
Get product
A6.1
Cleaned product
Crop residues
Harvester device
Requirement 10 &12
Transport target product
A6.2
Transporter device
Requirement 7
Store target product
A6.3
Storage device
Requirement 7: Time for harvest operation per kg of harvested product should be equal compared to sole cropping
Requirement 10: Combined weight of machinery + inputs/outputs should not reduce yields of intercrops
Requirement 12: Combine weight of machinery + i nputs/outputs should not produce soil compaction in the long term
Requirement 13: Soil Organic matter levels should be maintain according soil type
Product at Field Gate
O1
Requirement 13
crop residues on top soil
Return crop residues
A6.4
O2
I3
Crop's operation date
Powered+Moved+controlled working tool
I2
NODE:
A6
TITLE:
Harvest product
NUMBER: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DATE: 24/11/2014
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REV: 07/04/2015
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WORKING
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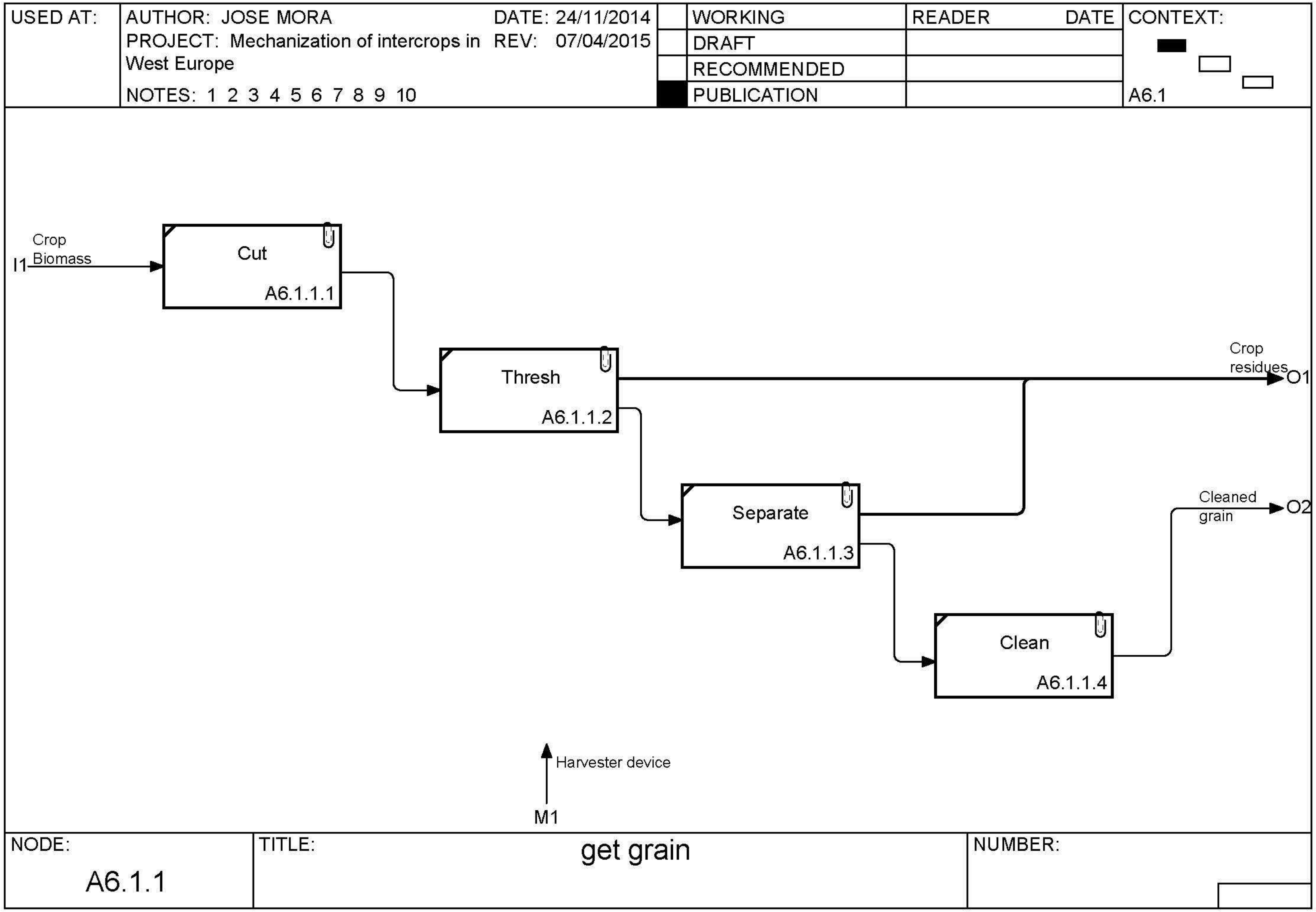
PUBLICATION
READER
DATE
CONTEXT:
A6
C1
Product location
C2
Crop's operation date
get grain
A6.1.1
Crop residues
O2
Cleaned grain
Product readiness state
I3
Crop Biomass
I1
I2
get roots
A6.1.2
Crop residues
Cleaned roots
Top soil profile
Crop residues
get leafs
A6.1.3
Cleaned product
O1
Harvester device
M1
NODE:
A6.1
TITLE:
Get product
NUMBER: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DATE: 24/11/2014
PROJECT: Mechanization of intercrops in West Europe
REV: 07/04/2015
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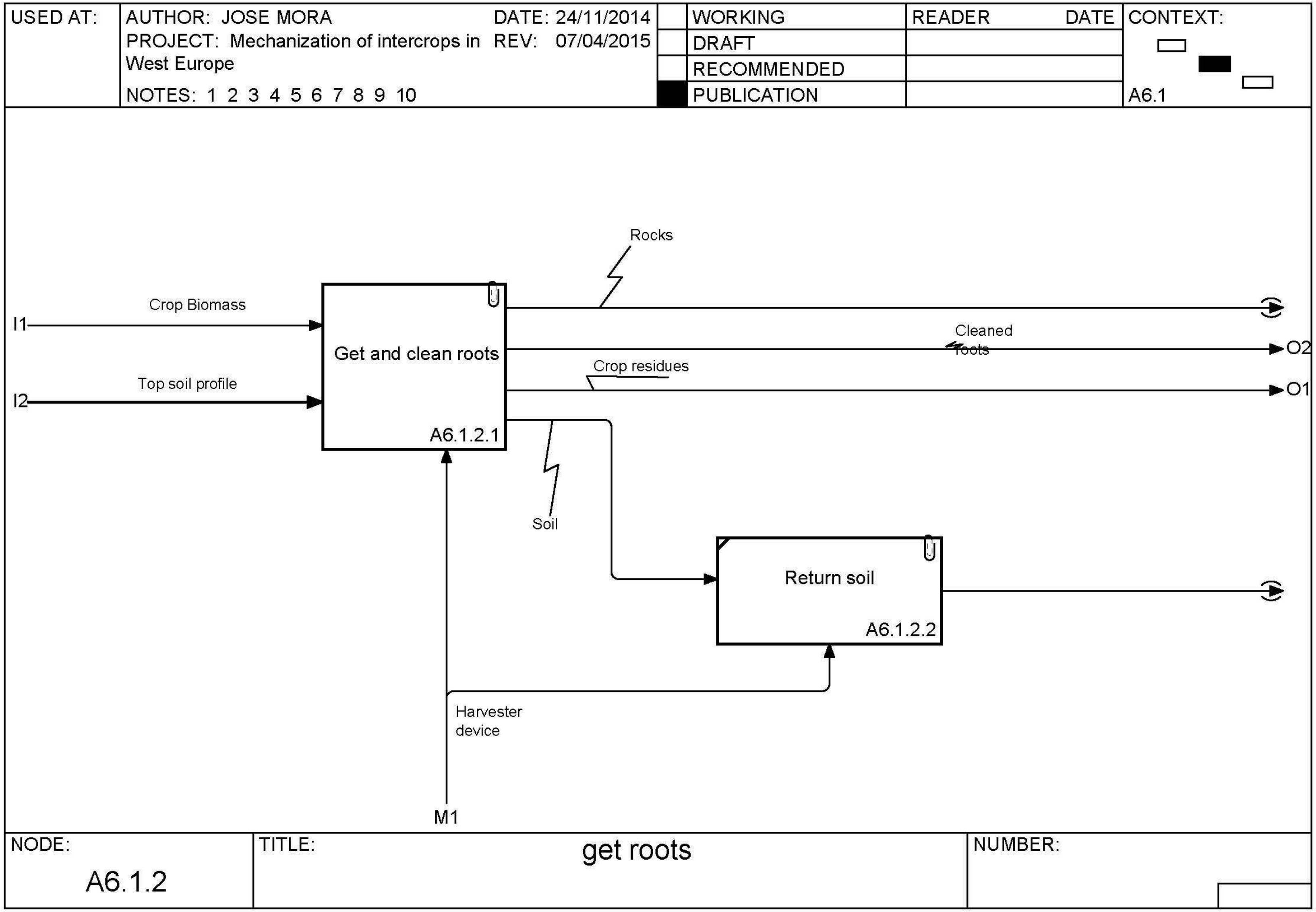
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A6.1
I1
Crop Biomass
Cut
A6.1.1.1
Thresh
A6.1.1.2
Separate
A6.1.1.3
Clean
A6.1.1.4
Crop residues
O1
Cleaned grain
O2
Harvester device
M1
NODE:
A6.1.1
TITLE:
get grain
NUMBER: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REV: 07/04/2015
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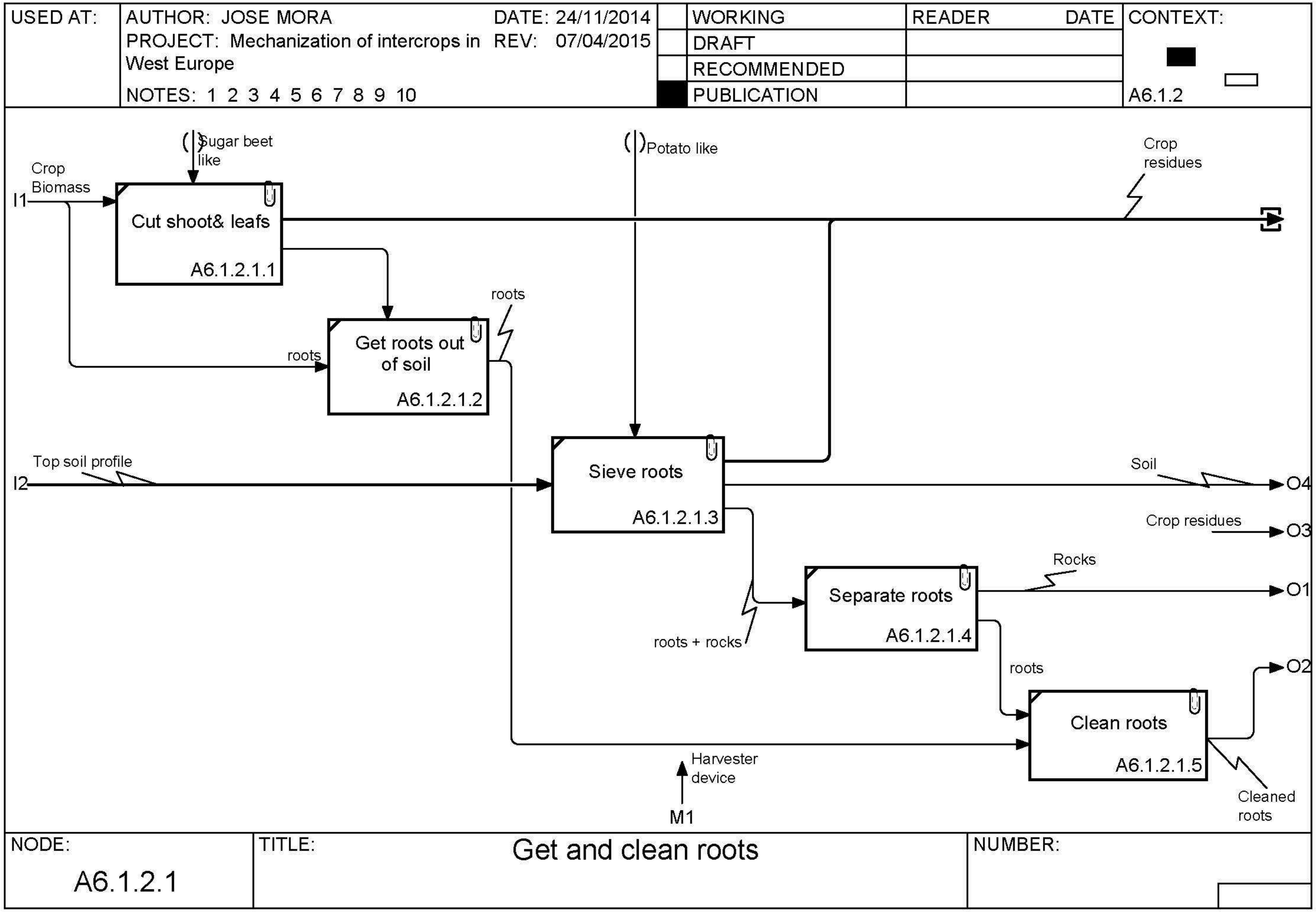
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A6.1
Rocks
Crop Biomass
I1
Get and clean roots
A6.1.2.1
Cleaned roots
O2
Crop residues
O1
Top soil profile
I2
Soil
Return soil
A6.1.2.2
Harvester device
M1
NODE:
A6.1.2
TITLE:
get roots
NUMBER: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REV: 07/04/2015
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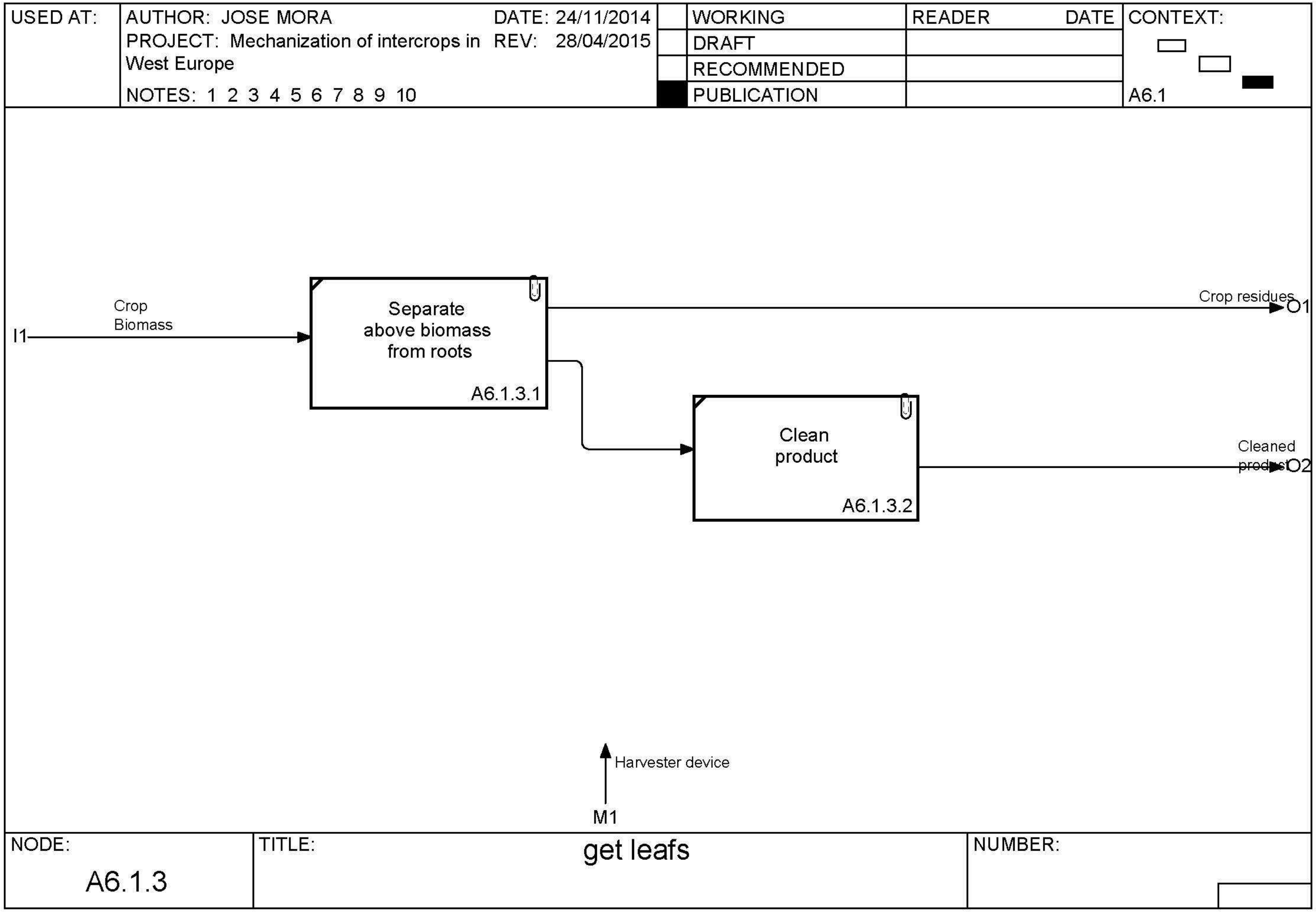
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A6.1.2
Sugar beet like
Potato like
Crop Biomass
I1
Cut shoot& leafs
A6.1.2.1.1
Crop residues
roots
Get roots out of soil
A6.1.2.1.2
roots
Top soil profile
I2
Sieve roots
A6.1.2.1.3
Soil
O4
Crop residues
O3
Rocks
O1
Separate roots
A6.1.2.1.4
roots + rocks
roots
O2
Clean roots
A6.1.2.1.5
Harvester device
M1
Cleaned roots
NODE:
A6.1.2.1
TITLE:
Get and clean roots
NUMBER: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DATE: 24/11/2014
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REV: 28/04/2015
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
A6.1
I1
Crop Biomass
Separate above biomass from roots
A6.1.3.1
Crop residues
O1
Clean product
A6.1.3.2
Cleaned product
O2
Harvester device
M1
NODE:
A6.1.3
TITLE:
get leafs
NUMBER:

Appendix 3: Scoring Current machinery solution

Index	Requirement description	Fixed Req.	Variable req.	Desirability	Variable/indicator	Min.value	Max.value	Target	Unit	Mean Scale (0-1-5)	SD	CV
1	Application of nutrients should match demands in terms of time and quantity of crop A and B, independently.		x		Agronomic nitrogen use efficiency for each crop growing period	0.4	0.7	0.7	Kg uptake d/Kg applie d	**3.25**	**1.00**	29%
2	Application of nutrients to crop A should diminish neither yield nor quality of crop B, and vice versa		x		Reduction in yield by phytotoxicity of nutrient spillover	0	3	0	%	**4.00**	**1.15**	29%
3	Application of Crop protection agent to crop A should diminish neither yield nor quality of crop B, and vice versa		x		Reduction in yield by phytotoxicity of herbicides spillover	0	3	0	%	**2.00**	**1.15**	58%
4	Application of Crop protection agents for crop A should not deposit on product of crop B and vice versa		x		Increment on Residues level in neighbor crop product as compared to the Maximum Residues Level of it.	0	2	0	%	**1.75**	**0.96**	55%
5	Crop protection agents emission to the environment should be reduced compared to sole cropping				Reduction of measured emissions	0	25	25	%	**4.00**	**0.00**	0%
6	Water should be accesible to crop A and B according to its respective evapotranspiration.		x		Irrigation use efficiency of each crop	70	90	90	Kg uptake /kg applie d	**2.25**	**1.60**	**71%**
7	Time for harvest operation per kg of harvested product should be equal compared to sole cropping		x		Variation of Total time/kg of harvestable product operation as compared to sole crops	0	5	0	%	**2.00**	**0.82**	41%
8	Machinery should be able to operate in of strip width of 3 meters	x			-	-	-	-	-			
9	Units labor per unit of harvested product should not be significantly greater than sole crops		x		Increment of Unit of labor per unit of harvested product as	0	5	0	%	**3.25**	**1.50**	46%

					compared to sole crops							
10	Combined weight of machinery + inputs/outputs should not reduce yields of intercrops		x		Yield reduction by short term soil compaction	0	5	0	%	**3.00**	**1.41**	47%
11	The Return on Investment should be equal or higher as compared to sole cropping system			x	Increment of ROI as compared to corresponding sole crops	0	5	5	%	**2.25**	**1.71**	76%
12	Combine weight of machinery + inputs/outputs should not produce soil compaction in the long term		x		Increment of Sub-soil compaction as compared to undisturbed soils	0	5	0	%	**3.25**	**1.71**	53%
13	Soil Organic matter levels should be maintain according soil type		x		Organic matter content (soil type dependent)	3	8	8	%	**4.75**	**0.50**	11%
14	CO2 foot print on products should be equal or lower than sole crops				Reduction in direct emissions of CO2 per unit of harvested product					**2.50**	**1.29**	52%
	Machinery operation of crop A should not harm the canopy of crop B	x			Photosynthesi s reduction of neighbor crop	0	1	0	%	**2.75**	**1.89**	69%
16	Machinery operation of crop A should not harm the roots of crop B				Damage of roots neighbor crop	0	1	0	%	**3.75**	**0.96**	26%
17	Machinery should be able to operate in scenarios of strip width of 1 meter.			x	-	-	-	-	-			