DIVERFARMING

Crop diversification and low-input farming across Europe: from practitioners' engagement and ecosystems services to increased revenues and value chain organisation

SELECTION OF CROP QUALITY AND NUTRITIONAL INDICATORS FOR EACH CROP AND REGION

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Executive summary

With the long-term view of increasing diversification and biodiversity in Europe (CAP objective) and fostering sustainable development of bioeconomy, the Diverfarming consortium has come together to develop and deploy innovative farming and agribusiness models. Diverfarming will increase the long-term resilience, sustainability and economic revenues of agriculture across the EU by assessing the real benefits and minimising the limitations, barriers and drawbacks of diversified cropping systems using low-input agricultural practices that are tailor-made to fit the unique characteristics of six EU pedoclimatic regions (Mediterranean South and North, Atlantic Central, Continental, Pannonian and Boreal) and by adapting and optimising the downstream value chains organization through executing 14 field case studies and 8 additional long-term experimental plots.

Within Diverfarming, WP3 aims to provide robust and sound data about how diversified cropping systems with low-input practices and efficient use of resources have positive effects on crop production and quality, and so, farm yields and economic revenues for farmers is increased. This can increase trading productivity with high quality outputs, so improving the competitiveness of European agriculture in the global market. In particular, this WP3 aims to: establish field experiments as case studies in the six pedoclimatic regions; assess the positive effects of the tailored diversified cropping systems on crop growth and farm yield; and assess the improvements in crop quality and nutritional characteristics with the adoption of diversified cropping systems.

For this purpose, the first step is to provide the selection of indicators for field and laboratory investigations, since every crop and pedoclimatic region is different and requires different parameters to assess crop quality and nutritional status.

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1. List of indicators and importance

Crop yield indicators

- Tree height: It is associated with growth form, position of the species in the vertical light gradient of the vegetation, competitive vigour, reproductive size, whole-plant fecundity, potential lifespan, and whether a species is able to establish and attain reproductive size between two disturbance events (such as e.g. fire, storm, ploughing, grazing).
- Trunk cross-sectional area: It is used to describe the tree's size, calculate its fertilizer requirements and determine the tree's potential value as a source of wood.
- Trunk diameter fluctuations: This measurement has attracted great interest, both for evaluating the water behaviour of the plant as well as for managing irrigation water more accurately.
- Leaf area index: It is defined as the ratio between the total leaf area of a tree and the area of soil occupied by the same tree. It is a parameter that allows measuring the productive efficiency of the soil occupied by the crop.
- NDVI: Different spectral indices have been proposed in recent decades, which, depending on the characteristic that one seeks to evaluate, has generated a large number of expressions applied to different studies in the vegetation. Among the most used is the Normalised Difference Vegetation Index (NDVI), developed to highlight the spectral signatures of vegetation between Red and NIR. Its application is extensive, with numerous prior studies that show the viability in the estimation of a large number of properties of the vegetation. Typical examples include the estimation of the leaf area index, the biomass, the concentration of chlorophyll in leaves, the productivity of the plants, the fractioned vegetation cover, the accumulated precipitation, etc.
- Stem water potential: The leaf water potential (Ψ) is, perhaps, the most frequently used parameter to define the water status of plants and to determine the moment to irrigate. It is commonly used as an indicator of the water status of fruit trees, and is affected by other factors, both of an environmental origin as well as of endogenous character, which causes variations in its levels based on the moment of the day and throughout the growing season, on the leaf age and the orientation and position they occupy on the tree. The measurement of Ψ is universally accepted as being the fastest, most reliable and most economical means of assessing the water status of plants.
- Net CO_2 fixation rate, transpiration rate and stomatal conductance: The stomatal conductance (g_s) is the variable that measures the degree of opening of the stomata situated on the leaves, by regulating the gaseous exchange with the atmosphere that surrounds it. This indicator of stress is affected by a large number of factors. Thus, its values depend on the light intensity, the temperature, the difference in absolute humidity between the leaf and the air, the age of the leaf, the concentration of CO_2 and the water potential itself. Photosynthesis is one of the most important processes in the plant response to water deficit conditions. It implies the coordination of different subprocesses such as the absorption of CO_2, the capturing of light by the chlorophyll-protein complexes, the synthesis of NADPH and the synthesis of ATP, among others.

- <u>Fruit growth:</u> Monitoring the fruit growth is a measure that many authors consider an indicator to take into account for irrigation scheduling, given that it allows us to differentiate the different crop phenological phases, even more so in those crops where the period that elapses from the fruit set until its harvest is extensive, as in the case of citrus or almond. It is likewise a measure that enables us to know the fruit status and predict much earlier when to harvest the crop.
- <u>Grape development</u>: These observations provide information about the physiological development of the grapevine and grapes indicating the maturity stage. This may show possible competition or benefit through the intercrop.
- <u>Sprout / stem diameter</u>: This parameter is easy to measure and provides information about the physiological development of the vine plant during early development stages. The sprout / stem diameter indicates growth-conditions in terms of availability of nutrients and water also as weather conditions (temperature, wind…) and may show some impact of the intercrop.
- <u>Flowering height</u>: This parameter is the main observation for the maturity stage of herbal crops, defining the harvest time. For *Origanum vulgaris* L. and *Thymus vulgaris* L. the best relation between yield mass and etheric oil concentration is present at beginning to full flowering. The height of the inflorescences – in addition with the plant width - is a good indicator for the plant growth and establishment success.
- <u>Crop establishment</u>: The field establishment of grain crops is the percentage of the sown seed that goes on to produce established plants. Successful crop establishment is crucial to achieve maximum potential yield. Factors affecting the establishment percentage include management factors such as depth of sowing, row spacing, seed size and herbicide application as well as environmental factors such as soil moisture and temperature. Timeliness of sowing is the most important factor followed by an evenly established and uniform plant stand. The procedure to measure establishment rate is very easy, inexpensive and requires little equipment.
- <u>Above-ground biomass</u>: Crop growth of arable crops can be controlled with measurement of the above-ground biomass. Despite above-ground biomass can be measured in different moments of the crop, measuring this parameter at flowering provides an excellent indicator of the crop growth at a critical crop development stage.
- <u>Carbon and nitrogen in leaves</u>: C and N elemental analysis provides a means for the rapid determination of C and N in organic and inorganic matrices. It is capable of handling a wide variety of sample types (including solids, liquids and viscous samples) in the fields of agricultural, food, chemicals, environment, pharmaceuticals and energy. It is a regulation mechanism of many metabolic and development processes in the plants.
- <u>Monitoring pests and diseases</u>: The objectives of sampling or monitoring are to detect the presence or absence of pests, quantify abundance of pests and their natural enemies and follow the progress of an arthropod population through time by regular, periodic sampling. The goal of monitoring is to reach a decision as to whether, or when, a pest population requires control action. Monitoring means checking your field to identify which pests are present, how many there are, or what damage they have caused. Correctly identifying the pest is key to knowing whether a pest is likely to become a problem and determining the best management strategy. After monitoring and considering information about the pest, its biology, and environmental factors, you can decide whether the pest can be tolerated or whether it is a problem that warrants control. If control is needed, this information also helps you select the

most effective management methods and the best time to use them. Pest populations vary from field to field, crop to crop and year to year. Managing pests requires flexibility and an absolute commitment to pest monitoring. Pest monitoring is site, crop and pest-specific. Each situation will require specialized knowledge and tools.

- Fruit production: It is a parameter that enables us to quantify the harvest to know the influence of the treatments in the trial. In addition, it serves to know yields of the harvest and commercial yields. The productive yield is an indicator that can be used to assess the crop response to the climate and/or other factors related with abiotic stresses, such as water deficit or saline stress. The different sizes of the fruit will be determined among the different treatments in order to determine the commercial value of the harvest.
- Marketable yield: It is parameter that enables us to quantify the harvest once those fruit which are not suitable for sale have been eliminated, to know the influence of the treatments in the trial.
- Cover crop yield: Cover crops are one of the most important agricultural practices that farmers can use to improve soil quality and increase the sustainability of their production system. Cover crops provide many benefits, including reducing erosion, fixing nitrogen (if legumes are included), and providing habitat for pollinators and beneficial insects. Their use also increase soil organic matter, infiltration rates, and nutrient availability. Knowing how much biomass (biomass dry weight per m^2) there is in a field is a critical piece of information for cover crop management.
- Land equivalent ratio: Land equivalent ratio (LER) is an essential indicator to assess the efficiency of intercropped agricultural systems. Intercropping is the cultivation of two or more crop species simultaneously in the same field for the entire or a part of their growing period. It is expected that intercrops use land and other resources more efficiently than monocrops. In fact, intercropping is a practical application of the principle of productivity increase by biodiversity. To really assess if intercropping is using resources more efficiently and delivers higher production per unit of land, the LER appears. LER is defined as the area of monocrops that would be required to obtain the same yield of the component crops as a unit area of intercrop. Thus, LER is useful to evaluate the benefit of intercropping compared to monocultures.
- Crop yield: It is a measurement of the amount of agricultural production harvested per unit of land area. Crop yield is the measurement most often used for cereal crops and is normally expressed in metric tons or kilograms per hectare (bushels or pounds per acre in the US). Alternatively, crop yield, which is sometimes referred to as “agricultural output”, can be defined as the amount of useful parts of a crop harvested at an appropriate development stage on a unit area. Crop yield is the weight of grain or other economic product, at some agreed standard moisture content, per unit of land area harvested per crop. Standard moisture content varies between crops but is 8–16% in grains. In all cases, grain moisture content is calculated on a fresh weight basis.

Crop quality indicators

- Fruit weight: It is an indicator of fruit quality and additionally enables us to know parameters such as the yield in kg ha^{-1} or kg $tree^{-1}$.
- Total soluble solids: The Brix scale is used in the agri-food sector to measure the approximate amount of sugars in fruit juice, wine or processed liquids within the agri-food industry, since in reality what is in fact determined is the total soluble solids (TSS) content. This indicator is used to monitor in situ the evolution of fruit ripening and the optimum moment for the harvest. In this way, the fruit TSS content is an indicator which allows us to know the juice's organoleptic properties.
- Juice pH: The pH is an indicator of the juice quality that allows us to know the organoleptic properties of the fruit. This indicator, together with the acidity, is one of the most important to assess the fruit quality given that it is closely related with the content of acids present, the capacity for microbial proliferation in conservation (low values will enable a longer useful life) since it will act on the fruit at physiological level as a natural physiological barrier against microbial action.
- Titratable acidity: The pH is an indicator of the juice quality that allows us to know the organoleptic properties of the fruit.
- Percentage of juice: This method provides information by means of the ratio of juice weight/fruit weight. It is an indicator of the fruit quality and additionally allows us to know other parameters such as the total titratable acidity, total soluble solids among others.
- Degree of acidity: The determination of free fatty acids in olive oils is an important quality factor and has been widely used as a criterion for the classification of olive oil into various commercial categories.
- Quality of fatty matter: Spectrophotometric examination in the ultraviolet radiation can provide information on the quality of a fat, its state of preservation and changes brought about by technological processes.
- Essential oils in aromatic species: Essential oils (EOs) are complex mixtures of volatile compounds extracted from plants, with a great interest in areas such as medicine due to their biocidal activities and medicinal properties, the pharmaceutical field where they are part of pharmaceutical base formulations, the food industry for food preservation and the textile industry where microspheres of EOs are used to improve the properties on textiles. EOs are highly volatile compounds, which are protected from external factors through encapsulation processes, and thus increasing their action duration.
- Sugar content: During maturity the sugar content of grape juice increases. Measuring the sugar content is one main method to define the maturity stage and quality of the grape juice.
- Thousand kernel weight: Thousand Kernel Weight (TKW) is one of the wheat quality parameters because it gives important information about the wheat's millability potential (i.e. extraction rate). In fact, wheat kernels with the similar size distribution but different TKW indicates that the heavier kernels have a higher percentage of endosperm than the lighter ones.
- Test weight: Test weight (TW) is a rough measure of the density of wheat (i.e. bulk density). This value is one of the factors of the market value of wheat, because in general it is directly related to the extraction rate of the milling products (i.e. semolina). Sound, clean, vitreous wheats with low moisture content tend to give the highest TW. One of the big disadvantages of

using TW in the today trade and processing is that the determined weight cannot be corrected to a dry or a fixed-moisture basis.

- Grain moisture: Like other factors of wheat quality (i.e. protein, ash, falling number) the moisture as well is greatly influenced by the growing and harvesting conditions. The original moisture of the wheat after the harvest affects its storability at the elevator. Normally, before milling the wheat is added of water (i.e. tempering) in order to bring the moisture between 14% and 17%. The water addition enhances the difference (i.e. toughness and friability) of the wheat's parts (i.e. endosperm, bran and germ) making milling possible.
- Grain protein: The quantity of protein is, together with their quality, one of the basic parameters for defining the wheat commercial value and the intended use of its relative milling products. The average content of the durum wheat protein is around 12 – 14 % (dry matter basis). The protein level is mainly genetically controlled (i.e. variety) but it is also influences by the environmental conditions and the agronomic practices applied (i.e. nitrogen fertilizers dosage).
- Grain ash: The ash content in wheat mainly refers to the presence of minerals in the grain. Wheat typically has an ash content of about 1.5%. The ash level is influenced more by the environment (i.e. geographic area, soil type, climatic conditions during the growth etc.) than by the genetic background. However, the ash is not distributed uniformly in the grain: the inner endosperm is relatively low in ash (about 0.3%), whereas the outer layers (i.e. the bran) may contain as much as about 6 %. Several countries have regulations concerning the ash presence of the wheat milling products (i.e. flour and semolina) for food destination. Therefore, the ash content in wheat is a very important factor for milling industries in terms of purchasing specifications. Since the semolina's ash is correlated with that of the whole kernel, the amount of semolina with a fixed ash content that can be obtained from a given quantity of wheat (i.e. the extraction rate) directly depends on the ash content of the wheat before milling.
- Grain gluten: Gluten is a general name for the proteins found in wheat, rye, barley and other cereals. Actually, gluten is a composite of storage proteins termed prolamins and glutelins and stored together with starch in the endosperm (which nourishes the embryonic plant during germination) of various cereal (grass) grains. Gluten gives elasticity to dough, helping it rise and keep its shape and often gives the final product a chewy texture. The wet gluten test provides information on the quantity and estimates the quality of gluten in flour samples. Gluten is responsible for the elasticity and extensibility characteristics of flour dough. Wet gluten reflects protein content and is a common flour specification required by end-users in the food industry.
- Grain screening: In the commercial channels the wheat is evaluated according to official grades defined by the wheat agency of a specific countries. The wheat's screening (i.e. everything is removed from the wheat before it is milled) effects the wheat values in terms of its storability, milling quality (i.e. extraction rate), end usage destination (i.e. human consumption, feed) and food security (i.e. possible presence of contaminants.
- Optical residue: This method provides information about the percentage of total soluble substances present in the tomato. A Brix degree (symbol Bx) corresponds to 1 part of solid substance (dry weight) in 99 parts of solution. For example, a 25 ° Bx solution contains 25 grams of solid substances in 100 grams of total liquid.
- Consistency: It is a fundamental parameter for the production of tomato pulp and each incoming load is subjected to measurement.

- Colour: It is a fundamental parameter for the production of concentrates and tomato pulp and each incoming load is subjected to measurement.
- Lycopene: It belongs to the class of carotenoids, or the vast class of liposoluble organic pigments. It has a series of positive properties of an antioxidant nature because it is a molecule rich in unsaturated bonds and is responsible for the red colour of the tomato. Lycopene is not synthesized by the body and its assimilation occurs through the intake of plant foods, first of all the tomato. It is soluble in oil and insoluble in water and is easily assimilated by the human body. In the tomato its presence is high at the level of the peel.
- Pesticides: All the agricultural products conferred must be produced according to the criteria established by the Integrated Production Regulation of the region of belonging and in any case in compliance with the minimum requirements set by Communitarian, National and Regional Regulations for the QC mark.
- Mineral composition: All the agricultural products conferred must be produced according to the criteria established by the Integrated Production Regulation of the region of belonging and in any case in compliance with the minimum requirements set Communitarian, National and Regional Regulations for the QC mark.

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2. Case study 1

Country: Spain

Crop: Rainfed almond

Diversification: Intercropping

Low input management: Reduced tillage

Crop yield indicators

- Trunk cross-sectional area
- Monitoring of pests and diseases
- Fruit weight
- Marketable yield
- Land equivalent ratio
- Tree height
- Leaf area index
- Net assimilation rate
- Crop establishment cover crop
- Above-ground biomass cover crop
- Fruit production
- Cover crop yield

Crop quality and nutritional indicators

- Essential oils in aromatics species
- Total soluble solids

3. Case study 2

Country: Spain

Crop: Irrigated citrus

Diversification: Intercropping

Low input management: Addition of compost, green manure, reduced tillage, deficit irrigation

Crop yield indicators

- Trunk cross-sectional area
- Monitoring of pests and diseases
- Fruit weight
- Marketable yield
- Land equivalent ratio
- Tree height
- Leaf area index
- Net assimilation rate
- NDVI
- Stem water potential
- Stomatal conductance and net photosynthesis
- Fruit growth
- Maximum daily trunk shrinkage
- Crop establishment cover crop
- Above-ground biomass cover crop
- Fruit production
- Cover crop yield

Crop quality and nutritional indicators

- Total soluble solids
- Thousand kernel weight
- Grain moisture
- Grain protein
- Juice pH
- Tritable acidity
- Percentage of juice

4. Case study 3

Country: Spain

Crop: Wheat in rainfed conditions (3.a) and maize in irrigated conditions (3.b)

Diversification: Crop rotation (3.a) and multiple cropping (3.b)

Low input management: No-tillage (3.a) and nitrogen fertilization management (3.b)

Crop yield indicators

- Monitoring of pests and diseases
- Crop yield
- Above-ground biomass at harvest

Crop quality and nutritional indicators

- Thousand kernel weight
- Grain moisture
- Grain protein
- Test weight
- Grain gluten (wheat)

5. Case study 4

Country: Spain

Crop: Olive

Diversification: Intercropping

Low input management: No-tillage and pruning mulch

Crop yield indicators

- Trunk cross-sectional area
- Monitoring of pests and diseases
- Fruit weight
- Marketable yield
- Land equivalent ratio
- Cover crop yield

Crop quality and nutritional indicators

- Total soluble solids
- UV absorbance
- Peroxide index
- Acidity
- Organoleptic analysis

6. Case study 5

Country: Italy (Lombardia Region)

Crop: Tomato and wheat

Diversification: Crop rotation and multiple cropping

Low input management: Reduced tillage and organic fertilization

Crop yield indicators

- Monitoring of pests and diseases
- Marketable yield (tomato)
- Crop yield
- Above-ground biomass at harvest

Crop quality and nutritional indicators

- Total soluble solids (tomato)
- Thousand kernel weight
- Grain moisture
- Grain protein
- Test weight
- Grain gluten (wheat)
- Grain ash
- Grain screening

7. Case study 6

Country: Italy (Emilia Romagna Region)

Crop: Tomato and wheat

Diversification: Crop rotation and multiple cropping

Low input management: Reduced tillage and organic fertilization

Crop yield indicators

- Monitoring of pests and diseases
- Marketable yield (tomato)
- Crop yield
- Above-ground biomass at harvest

Crop quality and nutritional indicators

- Total soluble solids (tomato)
- Thousand kernel weight
- Grain moisture
- Grain protein
- Test weight
- Grain gluten (wheat)
- Grain ash
- Grain screening

8. Case study 7

Country: Italy (Lombardia Region)

Crop: Tomato and wheat

Diversification: Crop rotation and multiple cropping

Low input management: Reduced tillage and organic fertilization

Crop yield indicators

- Monitoring of pests and diseases
- Marketable yield (tomato)
- Crop yield
- Above-ground biomass at harvest

Crop quality and nutritional indicators

- Total soluble solids (tomato)
- Thousand kernel weight
- Grain moisture
- Grain protein
- Test weight
- Grain gluten (wheat)
- Grain ash
- Grain screening

9. Case study 7BIS

Country: Italy (Apulia Region)

Crop: Tomato and wheat

Diversification: Crop rotation

Low input management: Residue management and reduced irrigation

Crop yield indicators

- Monitoring of pests and diseases
- Marketable yield (tomato)
- Crop yield
- Above-ground biomass at harvest

Crop quality and nutritional indicators

- Total soluble solids (tomato)
- Thousand kernel weight
- Grain moisture
- Grain protein
- Test weight
- Grain gluten (wheat)
- Grain ash
- Grain screening

10. Case study 8

Country: The Netherlands

Crop: Fodder crops and potatoes

Diversification: Intercropping

Low input management: Organic fertilization and green manure

Crop yield indicators

- Monitoring of pests and diseases
- Crop yield

Crop quality and nutritional indicators

- Total soluble solids (potato)

11. Case study 9

Country: Germany

Crop: Vineyards

Diversification: Intercropping

Low input management: Organic production, organic fertilization, no-tillage

Crop yield indicators

- Trunk cross-sectional area
- Monitoring of pests and diseases
- Fruit weight
- Marketable yield
- Land equivalent ratio
- Crop yield of the cover crop

Crop quality and nutritional indicators

- Total soluble solids
- Sugar content
- Mineral composition
- Tritable acidity
- Juice pH

12. Case study 10

Country: Hungary

Crop: Horticulture

Diversification: Intercropping

Low input management: Green manure, green soil

Crop yield indicators

- Monitoring of pests and diseases
- Fruit weight
- Marketable yield
- Land equivalent ratio
- Crop yield of the cover crop

Crop quality and nutritional indicators

- Mineral composition
- Fiber

13. Case study 11

Country: Hungary

Crop: Vineyards

Diversification: Intercropping

Low input management: Green manure, green soil

Crop yield indicators

- Trunk cross-sectional area
- Monitoring of pests and diseases
- Fruit weight
- Marketable yield
- Land equivalent ratio
- Crop yield of the cover crop

Crop quality and nutritional indicators

- Total soluble solids
- Mineral composition
- Tritable acidity
- Juice pH

14. Case study 12

Country: Finland

Crop: Barley

Diversification: Crop rotation

Low input management: No-tillage

Crop yield indicators

- Monitoring of pests and diseases
- Crop yield
- Above-ground biomass at harvest
- Below-ground biomass at harvest

Crop quality and nutritional indicators

- Thousand kernel weight
- Grain moisture
- Grain protein

15. Case study 13

Country: Finland

Crop: Barley

Diversification: Crop rotation

Low input management: Organic production

Crop yield indicators

- Monitoring of pests and diseases
- Crop yield
- Above-ground biomass at harvest
- Below-ground biomass at harvest

Crop quality and nutritional indicators

- Thousand kernel weight
- Grain moisture
- Grain protein