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Chapter 15
Crop Management for Breeding Trials

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Abstract Appropriate agronomic management of breeding trials plays an important role in creating selection conditions that lead to clear expression of trait differences between genotypes. Good trial management reduces experimental error to a minimum and in this way facilitates the detection of the best genotypes. The field site should be representative for the target environment of the breeding program, including soil and climatic conditions, photoperiod, and pest and disease prevalence. Uniformity of a field site is important to provide similar growing conditions to all plants. Field variability is affected by natural and management factors and leads to variability in crop performance. Additionally, pest and disease incidence tend to concentrate in patches, introducing variability not necessarily related to the susceptibility of affected genotypes. Precise agronomic management of breeding trials can reduce natural field variability and can contribute to reduce variability of crop performance. Through specialized agronomic management, contrasting selection conditions can be created in the same experimental station. The use of adequate machinery like plot seeders and harvesters contributes to precise trial management and facilitates operation. Machine seeding assures even seeding depth and density. Plot combines can be equipped with grain cleaners, on-board weighing systems and sensors to measure grain humidity and weight, which can greatly facilitate data collection.

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15.1   Learning Objectives

- To understand the experimental error of field trials and ways to reduce it.
- To understand the importance of agronomic management for creating appropriate selection environments.

15.2   Introduction

Field experimentation is an essential part of plant breeding programs. Appropriate agronomic management of breeding trials plays an important role in creating selection conditions that lead to clear expression of trait differences between genotypes. Good trial management reduces random variation (experimental error) between plots (smallest experimental unit) to a minimum and in this way facilitates the detection of the best genotypes.

During the different selection stages throughout the breeding process, different kinds of experimental layouts and experiment management are needed, including different types of machinery (Fig. 15.1). For example, the seeds obtained from an initial cross might be sown in short rows by hand, but later generations are sown mechanically in plots and might be tested under various environmental conditions and in several locations. Traits like plant height, maturity and disease resistance can be measured in very small plots, while realistic yield estimates require large plots. Through specialized agronomic management, contrasting selection conditions can be created in the same experimental station, for example optimum vs. low nutrient or optimum vs. reduced irrigation environments. Selection environments (SE) are usually created through a combination of natural site characteristics and modifications by agronomic management.

Although genetic and genomic data have been becoming more and more important in plant breeding, data obtained from field trials do not lose their significance. It is under varying field conditions where the plants must perform and ultimately those data can only be obtained from practical experiments. Techniques, like genomic selection, require accurate field experimentation, since data from field trials are used to predict performance of untested populations. The quality of the prediction also depends on the quality of the phenotypic input data.

The chapter is divided into two parts. The first part treats the selection of field sites, the creation of selection environments through agronomic management and mechanization of breeding trials. The second part deals with experimental error and ways to reduce its impact in field experimentation.

Fig. 15.1 Test plots of different sizes at CIMMYT's experiment station in Ciudad Obregon, Mexico. (Image by Lorena González/CIMMYT)

15.3   Selection and Management of Field Sites

The field site should be representative for the target environment of the breeding program [1]. This includes soil and climatic conditions, photoperiod, and pest and disease prevalence. Some conditions can be created artificially; disease pressure can be increased through artificial inoculation or generation of humid environments where pathogens thrive. In arid environments, different levels of drought stress can be mimicked through irrigation practices. Creation of environments the opposite way around is more challenging; mimicking drought in humid environments needs for example rainout shelters and keeping trials disease free in areas with high disease pressure would need large amounts of pesticides. Air temperature (and vernalizing cold) are impossible to change in field trials but photoperiod can be extended using low intensity lamps. The 'modifiability' of an environment should be considered if genotypes are to be tested under different conditions in the same site.

Uniformity of a field site is important to provide similar conditions for all genotypes grown in an experiment or nursery. It is affected by natural and management factors (field history). Natural factors include soil characteristics, but also landscape aspects, like hills, slopes, depressions, or rows of trees that cause shading in some areas of a field. Heterogeneous soil conditions can be caused by previous experiments, through different types of management. Fertilization or tillage experiments can lead to patchy soil conditions. An ideal field site is flat with homogeneous soil conditions and without shading. However, these ideal experimental sites are often not available, and some degree of heterogeneity is present [2]. It is important to

know the variability of the experimental area, recognize possible impacts and take them into consideration for trial layout and analyses.

15.3.1 Agronomic Techniques for Creation of Selection Environments

Selection environments are the trials that breeders use to make selections for desired traits. The SE must be designed (or chosen) in a way that maximizes the power of prediction for performance in the target population of environments (TPE) (see Chap. 3). Careful trial management is necessary to create selection conditions that are similar to the ones found in farmers' fields where the new varieties eventually need to succeed. Certain aspects of SE can be created or influenced by agronomic management, those include for example water and nutrient availability and disease pressure. The 'Quick facts' Table 15.1 provides a summary of agronomic factors to be considered in breeding trials.

Drought is the most important abiotic stress worldwide. Drought often appears in conjunction with other abiotic stresses, like high temperatures and high radiation (see Chap. 10). While it is common to generate artificial drought conditions for breeding trials and agronomic experiments, accompanying factors are difficult to create artificially in field trials and therefore are usually neglected. A difficulty of drought stress experiments is that drought can appear in many different ways, at different growth stages and with different intensities. For example, drought can be caused by constant reduction of soil humidity throughout the season. Or a lack of water could appear even though regular rainfalls are present, but those are not intensive enough to meet crop demands. In the first case the stress level is rising over time, while in the second case water availability might stay low but constant. Sometimes strong rainfalls alternate with prolonged drought phases, exposing crops to extremely contrasting conditions within one cropping cycle. It is important to define the type of drought stress that is to be mimicked in a selection environment.

Arid regions are naturally the most appropriate places to conduct drought stress experiments. In arid regions, where irrigation is a prerequisite for crop cultivation, different amounts of irrigation water and types of irrigation can be used to create relevant drought stress environments. In humid regions, rainout shelters can be used to create drought experiments. Those shelters can be fixed or mobile. The latter version has the advantage that it only covers the crop during precipitation events and therefore allows the crop to be exposed to natural radiation and wind conditions during the rest of the time [3]. Lateral water flow can be a constraint in drought experiments with rainout shelters and soil humidity needs to be monitored throughout the experiment.

Nutrient availability can vary widely from field to field in the same target environment. Economic constraints that do not allow farmers to buy fertilizer or simply the lack of products to purchase are important reasons. Low input systems, like

Table 15.1 Quick facts 'Important agronomic factors to consider in breeding trials'

Factor	Impact/Relevance
Representativeness	Soil and climatic conditions, photoperiod, pest and disease prevalence and agronomic management of the field site should be representative for target environments.
Field history	Previous experiments can lead to patchy field conditions and may require a uniformity treatment to achieve homogeneous conditions.
Nutrient management	Optimum nutrient supply can even out heterogeneous soil conditions and is required for expression of maximum yield potential.
	For a low nutrient selection environment, the field plot needs to be depleted prior to start of selection, only target nutrient should be limited.
Weed control	Weeds should be controlled to avoid competition with crop.
Pest and disease control	Pest and diseases need to be controlled for maximum expression of yield potential.
	Favorable conditions for pests and diseases can be created if resistance or tolerance are part of the breeding targets.
Soil management	Tillage, direct seeding, removing or leaving crop residues and their combinations lead to different germination conditions. Soil management should be representative for the target environment.
Irrigation	Different types of irrigation, like drip, furrow and sprinkler irrigation differ in the way they make water available to plants and should be chosen according to the most common technique used by farmers in the target population of environments.
Crop rotation	Appropriate crop rotations improve nutrient status and reduce pathogen pressure in the field. To keep the field healthy, wheat should be rotated with non-cereal crops.
Lodging	Lodging can be reduced by timing of N application and irrigation, reducing plant stand, growing plants on beds and the application of growth regulators.

organic farming, require genotypes with high nutrient use efficiency under low nutrient conditions as well. Ideally, efficient genotypes are also highly responsive when additional nutrients are available. Selection and evaluation under both low and high nutrient conditions allows researchers to identify genotypes that perform well under both conditions [4]. In order to create those environments, the soil nutrient status needs to be analyzed prior to trial establishment. This is especially important for the establishment of low nutrient selection environments. If nutrient levels are too high, a uniform crop needs to be grown without fertilizer addition to remove excess nutrients. If a particular nutrient, e.g. N, is to be removed it needs to be assured that all other nutrients are sufficiently available so that crop growth is only limited by the target nutrient. Soil nutrient status should be monitored regularly to assure the desired level is maintained.

Conservation agriculture (CA) is a form of agronomic management that consists of minimum tillage, maintaining crop residues on the soil surface and crop diversification. This type of management can improve soil health and water availability. Soil cover and higher top soil bulk density compared to conventional tillage conditions can be a constraint for early crop development. Certain diseases, e.g. Fusarium

head blight and Yellow leaf spot can be favored by retention of crop residue, especially in monoculture or certain crop rotations (e.g. wheat-maize). Most breeding programs operate under conventional tillage conditions and the special conditions caused by CA are not included as SE. The area where wheat is grown under CA is expanding, also due to promotion by national and international organizations. Therefore, it is an important question whether CA requires varieties with different characteristics compared to those used in and developed under conventional tillage conditions. Characteristics discussed as especially beneficial are strong early vigor and disease resistance. CIMMYT's durum wheat breeding program conducted a parallel selection experiment under conventional tillage and CA conditions. Subsequently all genotypes from both selection streams were evaluated under both tillage regimes. For the case of CIMMYT's widely adapted durum wheat material no relevant difference between selection under conventional tillage or CA were detected [5]. These results indicate that for the conditions tested, there is no need for specialized breeding programs and selection can take place under CA without negative consequences on genotype performance under conventional conditions.

Selection environments with high disease pressure can be created through management suitable to create conditions where disease thrive. Humidity is an important factor that can be manipulated through sprinkler irrigation (Fig. 15.2). High plant stand densities and monotonous crop rotation that favor the development of plant diseases and pests are ways to create relevant conditions.

15.3.2   Mechanization for Breeding Trials

Breeding trials follow specific designs with numerous small plots arranged to grow a wide array of genotypes. Often a considerable amount of seeding and harvest operations in breeding programs is done by manual labor. Manual operations are highly labor-intensive, especially for sowing and harvest, and can result in more variable seeding depth and spacing due to human error. Therefore, specific experimental machinery has been developed that can handle precision plot sowing and harvest, reducing variability and speeding up operations.

15.3.2.1   Plot Seeders

Limited plot sizes and randomized plot designs require accurate seed metering that can respect the complex lay-out of small plots or rows of genotypes to be tested, often placed at short equidistant intervals or at varying densities. Small-seed plot seeders uniformly distribute a measured or counted quantity of seed per surface area unit (Fig. 15.3). Cone seeders are the most common type, as these can handle very small amounts of seeds and do not require large amounts of seed to be held in hoppers as is the case for conventional planters. During sowing, manually prepared seed

Fig. 15.2 Artificially created humid environment using sprinklers to create optimum conditions for fusarium screening at CIMMYT's headquarter El Batán, Mexico. (Image by Pawan Kumar Singh/CIMMYT)

packages or seeds preloaded in cartridge arrays are dropped on top of a cone-shaped plate and released or 'tripped' at the start of each plot or plant row (Fig. 15.4).

With seeds evenly distributed at the bottom of the cone, the latter revolves to deposit the seeds to the soil as the machine advances. Newer systems allow electronic calibration of cone revolution speed to match plot length, while older systems use a clutch in combination with a mechanical gear box. Depending on experimental layout, multiple seed tubes that deliver seed to the soil can be connected to a single cone seed meter to plant several plant rows simultaneously, or alternatively, multiple cone meters can be placed on a seeder. The use of multiple cone meters allows to sow different genotypes with each cone (for plots that are half the machinery width, two cone seed meters would be mounted – Fig. 15.3) or the same genotype (with plots width matching the machine's). If multiple seed tubes are connected to a single cone seed meter, it is necessary to include a motorized divider mechanism to evenly distribute the seed among the tubes. Next to seed meters and similar to regular planters, soil penetration and seeding depth can be configured using opening tines or disc coulters depending soil conditions, followed by pressing wheels for adequate soil-seed contact to promote germination. Precision sowers allow for seed singulation, i.e. sowing individual seeds separately along the row at a defined spacing. These are already available for commercial sowing of many crops and are becoming available for plot sowing, potentially playing a role in breeding in the future.
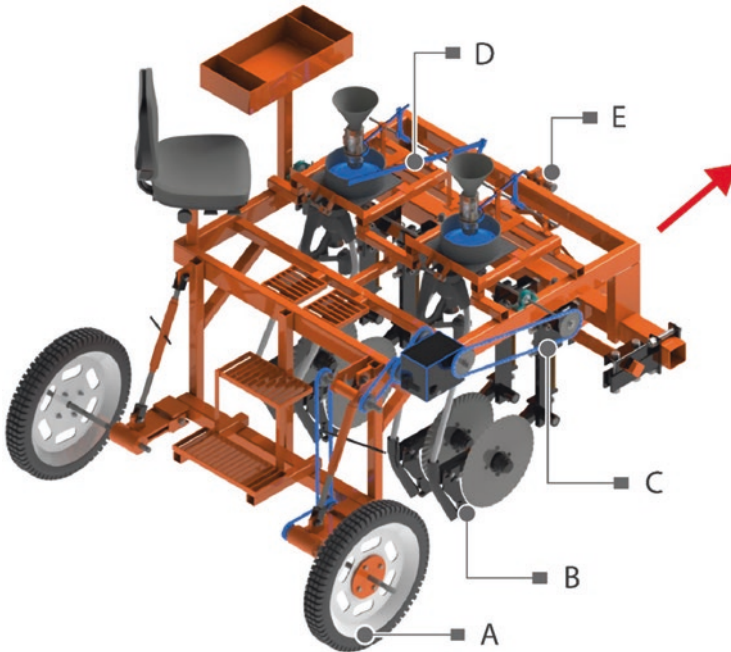
Fig. 15.3 Experimental plot seeder with two cone-shaped seed meters and mechanical drive train (marked blue, *C*) for seed distribution, with (*A*) traction wheel, (*B*) disc coulters (optional in case of crop residue) and seed delivery tynes, calibration mechanism with black gear box, and (*D*) operating lever to release seeds on cone-shaped metering device. This model is designed to be pulled by a tractor with three-point hitch (*E*), while self-propelled models also exist. Red arrow indicates direction of movement during operation

15.3.2.2 Machinery for Harvest

Similar to plot seeders, specialized farm machine manufacturers offer a variety of self-propelled experimental harvesters and mini-combines. Critical steps during harvest are the cutting of ears which, if done with inadequate equipment, can cause significant grain losses, and threshing where yield losses occur due to grain damage. The choice of mechanized harvesting for experimental plots depends on plot size, harvest volume and final objective. Despite their reduced size, the front-end of experimental harvesters remain largely similar to commercial grain harvester combines, consisting of a pickup reel, cutter bar and thresher drum. Plot combines can be equipped with grain cleaners, on-board weighing systems and sensors to measure grain humidity and weight, which can greatly facilitate data collection. Bagging options and crop dividers for continuously harvesting of experimental plots are all part of the possibilities and choices to consider. Adjusting harvesting speed and minimal machine vibration help reduce the amount of grain that falls outside the header.
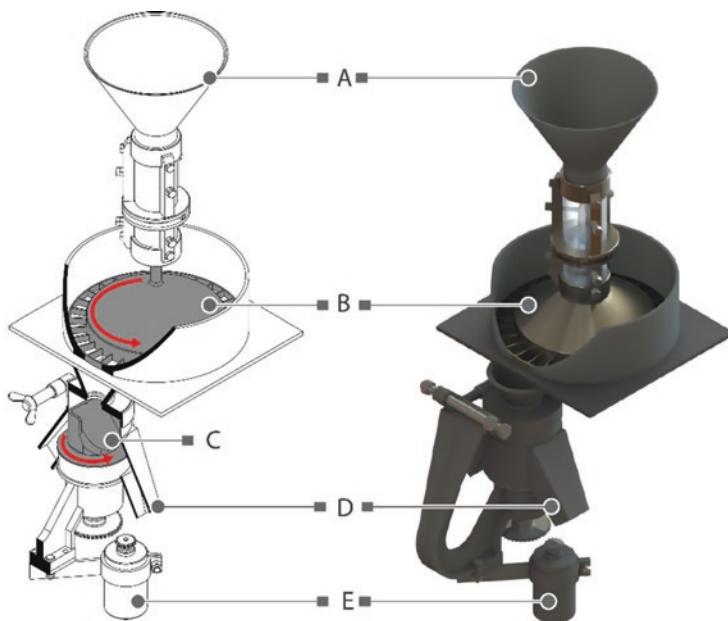
Fig. 15.4 Schematic representation of experimental cone seed meter system in open (left) and closed (right) position: (*A*) seed insertion funnel, (*B*) cone-shape seed distribution plate, (*C*) seed divider mechanism to distribute seeds evenly among tubes, (*D*) seed tubes entry, (*E*) electric motor that drives divider system. Red arrows indicate revolving movement of cone and divider mechanism during operation

15.4   The Experimental Error

Experimental error is a term used to describe variation that occurs among plots that receive the same treatment. Two types of error are distinguished – random and systematic. The random error is not a mistake due to poor trial management. Rather it describes the slight variation that exists even if all management is carried out in the most careful way. Sources of this variation are for example differences between plants of the same genotype, natural soil variability, topographic gradients, measurement inaccuracies, etc. Systematic errors follow a constant pattern. They usually occur due to incorrectly calibrated instruments or equipment. Experimental errors can never be eliminated completely but should be reduced as much as possible. Common sources of error are described below. Besides the reduction of experimental error, appropriate experimental designs, including appropriate blocking of replicated trials and statistical analyses are essential for its precise estimation (see Chap. 13).

15.4.1 Avoid Systematic Errors

Systematic errors can occur at many points in the process of field experimentation. They are not always easy to detect, because they affect all measured values in the same way. An example is a wrongly calibrated scales that adds 10 g to each sample. Or an incorrectly designed measuring stick where the number of plants is counted along 90 cm instead of 1 m. The experimenter can also be the source of error, by constantly making the same mistake, e.g. putting 40 g of seed in every seeding envelope instead of 50 g leading to incorrect seeding rates. Low germination rates due to poor seed storage conditions can be a factor that strongly influences yield per plot. Other sources of error can be wrong calibration of planters, mistakes numbering or arranging field entries and weighing errors at harvest. And there are many more! While it is not possible to have a complete list of all possible sources of error, it is even more important that the experimenter has possible sources in mind, and organizes and documents every step of the trial in order to be able to detect systematic errors.

15.4.2 Minimize Field and Management Variability

Variability in crop performance can be due to variability in the availability of soil and above-ground resources or field operations. Additionally, pest and disease incidence tend to concentrate in patches, introducing variability not necessarily related to the susceptibility of affected genotypes. Precise agronomic management of breeding trials can reduce natural field variability and can contribute to reduce variability of crop performance.

Variability in resources only results in spatial variability in crop development when the resource is limiting crop performance [6]. Shatar and Mcbratney [7] examined relationships between sorghum yield and soil properties in Australia and found that most of the measured soil properties varied spatially, but only a few were responsible for variation in yield. Along the field boundaries, changes in the amount of plant available water mostly caused variation in sorghum yield, while in the center of the field, soil held more water so that production reached a level at which the potassium content limited production. Machado et al. [8] reported a positive effect of soil NO_3-N on sorghum grain yield in a year when water was abundant, but a negative effect in a year when water was limited.

Within-field spatial variability can be the result of inherent variation in field conditions. However, agronomical practices also influence spatial within-field plant variability. Kravchenko et al. [9] found that in a zero-input treatment, overall variability (coefficient of variation) was significantly higher compared to treatments with low or conventional input. In semi-arid highlands in Mexico, conservation agriculture, i.e. zero tillage with residue retention and wheat-maize rotation, resulted in high soil health and uniform crop performance, while under zero tillage with

residue removal, soil health and crop performance followed micro-topography with higher values where micro-topography was lower [6].

For breeding trials, researchers should use agronomic management that maximizes the uniformity in the distribution of resources and results in vigorous crops, like conservation agriculture, only inducing stresses that represent the chosen selection environment. Appropriate crop rotations help to eliminate variability due to previous trials and reduce the disease and weed seed burden.

Lodging introduces variability, because it tends to occur in patches related to micro-topography, wind- and rainfall patterns and a domino-effect where lodging-prone genotypes drag down neighboring plots (Fig. 15.5). Several agronomic management practices can minimize lodging. The most commonly used management factors to minimize lodging are reduced or delayed N fertilization and reduced seeding density [10]. Planting systems can decrease lodging, for example, bed planting with furrow irrigation had over 50% less lodging than flat planting with flood irrigation in Mexico [11]. Plant growth regulators can reduce lodging by decreasing plant height and increasing the physical strength of the basal part of the culm internode [12]. If management in SE is optimized to minimize lodging, while these management factors are different in areas where the materials will be used, materials should be screened under lodging-inducing conditions before they are released to screen out materials prone to lodging.

Fig. 15.5 Logged plots surrounded by standing plots at CIMMYT's experimental station in Ciudad Obregon, Mexico

Researchers should carefully design and monitor field operations to minimize errors. The protocol of each experiment should include a field management plan with an overview of options to manage common problems, like pests, diseases and weed pressure in the experimental field. This includes options of pesticides available in the area and preferably threshold values for pest incidence that require their use. Weed, pest and disease incidence and the technologies for their management tend to evolve rapidly, so it is important to collaborate with pathologists, agronomists, weed scientists to get the latest insights and updated technologies. When working at an experimental station, station managers can offer experience and insight and should be involved in discussion to stimulate continuous improvement of agronomic management of wheat breeding experiments.

During the growing season, researchers should prepare detailed instructions for all operations, adjusting field management to the development of the growing season, since weed pressure, disease and pest incidence are highly variable and dependent on weather conditions. Regular monitoring of the field is essential to ensure any problems are caught early and can be managed before they introduce variability that affects the experiment. Walk-throughs should be done at least twice a week.

It is important to keep detailed records of all field operations, to allow a good description of experimental conditions for reports and publications, to spot potential problems and to design and monitor improvements in management over time. When pesticides are used, active ingredients with different modes of action should be varied in time, to prevent the development of resistance and this can be monitored through these records. The records of field operations should include dates, products used (concentration of active ingredients, dose used), names of the persons executing field operations and preferably also time of day, since that affects effectivity of certain active ingredients. For certain types of operations, e.g., tillage operations, a more detailed description is necessary (e.g., including tillage depth, implements used), but these can be made once, using a brief description from then on (e.g., 2 passes of disking). Keeping a physical copy of the operations records in a visible place, can help make sure that records are always up-to-date and emphasize the importance of careful management and record keeping.

Variability in field operations that can cause variability in crop performance includes uneven applications of inputs like fertilizer, irrigation water or pesticides and errors in sowing, like clogged tubes. To prevent these errors, it is important to regularly revise and give maintenance to machinery and equipment, give detailed instructions on calibrations, make sure that field operators have a good understanding of machinery and equipment calibrations and their importance for the validity of the research and to check machinery calibrations before field operations. Again, frequent field monitoring is important to spot mistakes and, where possible, correct them before they affect the outcome of the experiment.

15.4.3   *Account for Soil Variability*

Field heterogeneity is caused by natural soil heterogeneity and topography, agronomic management and previous experiments – the field history. Some variation is present in all experimental sites. The degree of heterogeneity however varies. In an ideal site variation is low (i.e., does not affect yield in a significant way) and does not need to be considered in the trial design. However, often a considerable field variability is present, resulting for example in a productivity gradient. Highly variable field sites produce highly variable phenotypic data and can mask true genetic differences between genotypes. Therefore, it is important to assess field variability and account for it with experimental design and/or with spatial analyses [13].

It is important to know the field history. In some cases, significant variability is caused by previous experiments and/or agronomic management. Different types of tillage or fertilization experiments can lead to patchy distribution of soil conditions. In some cases, a uniformity treatment of the experimental area is necessary to create homogeneous conditions. In case of previous fertilizer experiments for example, it is advisable to cultivate crops without fertilizer to extract nutrients and achieve a homogeneous nutrient status in the experimental area before starting experiments or selections. Different types of soil management, like plowing, zero tillage, removing or leaving of plant residues also affect soil quality and uniformity treatment should be considered.

Natural soil heterogeneity can hardly be changed but can lead to very different growing conditions even at short distances. Soil texture or depth, for example can vary and influence nutrient and water availability, which in turn leads to different levels of productivity. Soil and yield maps help to identify similar areas and allow the experimenter to choose appropriate trial layouts.

Field heterogeneity can be measured by growing uniformity trials. The experimental area is sown with one variety and treated uniformly. For harvest the area is divided into many small plots (the smaller the more precise) and yield for each plot is determined separately. The result is a yield map that enables the identification of more and less productive areas.

Instead of manual harvest, uniformity can also be assessed in automated ways using sensors. Yield monitors mounted onto combines in combination with differentially-corrected global positioning system receivers enable the automated collection of georeferenced yield data and subsequent creation of high-resolution yield maps. This way of yield monitoring is a common application in precision agriculture and can be a valuable instrument in trial planning.

Remote sensing technologies enable rapid, non-destructive mapping of areas with high and low productivity within fields (see Chap. 27). Vegetation Indices (VI) based on multispectral remote sensing are a standard method for monitoring crop growth and can provide estimates for grain yield in wheat through correlation analyses [14]. One example of a widely used VI is the Normalized Difference Vegetation Index (NDVI), which uses red and infrared bands to estimate canopy growth. In
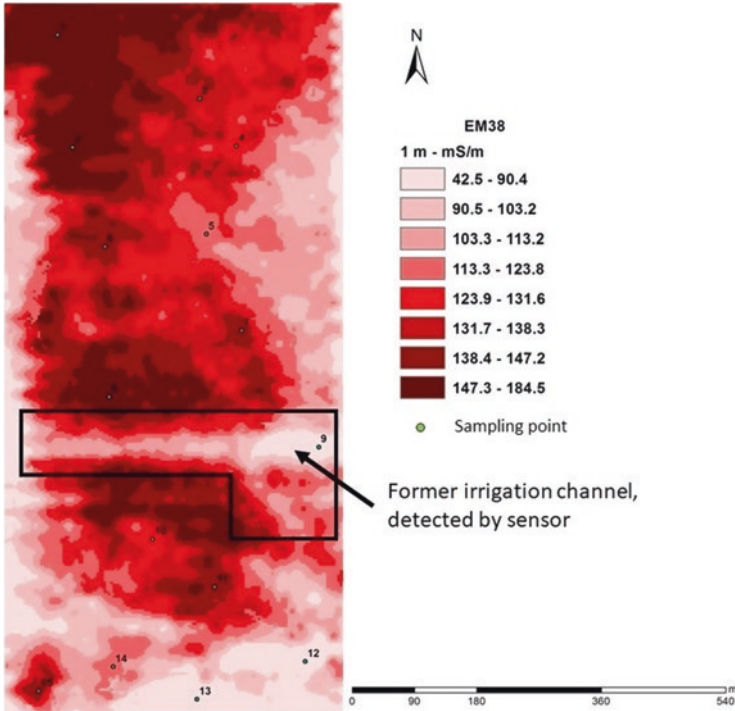
Fig. 15.6 Field map showing soil heterogeneity by differences in electrical conductivity measured with the conductivity meter EM-38. (Modified with permission from [16])

wheat this index is widely used to monitor crop growth throughout the growing cycle and to estimate grain yield.

Yield and productivity maps serve as a proxy for the assessment of soil heterogeneity. Proximal soil sensing is an established way to assess soil characteristics and create soil maps. An established parameter is apparent soil electrical conductivity (ECa). Georeferenced ECa measurements are used to create soil maps that enable estimates of heterogeneity (Fig. 15.6). ECa measurements are used to map variation of soil salinity, clay content, soil water content and organic matter [15].

15.4.4 Border Effects

In plant breeding programs and genetic studies large numbers of genotypes need to be tested in field trials. Due to resource constraints, usually, the area per genotype is reduced with growing number of genotypes tested. Growing conditions in very short rows containing only a few seeds are very different compared to commercial fields. In the latter all plants are of the same genotype. In test fields with small plots, difference in plant height and canopy architecture between adjacent plots can lead

to confounding effects when rating plant performance. Especially for complex traits like yield, this poses challenges. Reduction of yield was observed with growing height of plants in adjacent plots [17]. When gaps are narrow, intergenotypic competition between neighbors is growing. The leaf angle can also contribute to inter-plot competition. Genotypes producing more horizontal leaves gain more space in competition across a gap path row. Such genotypes benefit especially from large gaps between plots, because they are able to spread horizontally below and above ground to obtain more gap resources. Ideally plots are large enough to allow the removal of border and harvest only the inner rows. In this way, confounding effects of adjacent plots are largely removed [18]. Most of the time, especially in early generations this is not feasible and the whole plot can be harvested for expedience. End-trimming to reduce the effect of the (unnatural) lateral space between plots is a compromise when harvest of inner rows only is not possible. It is important that no large gaps exist between plots and that the spacing between plots is always the same, to avoid introducing additional variability.

15.5   Summary

Appropriate agronomic management of plot trials (1) chooses the location or creates the general field test environment which favors the traits that the breeder wishes to measure, and (2) reduces experimental error to a minimum in the test. The latter assures the breeder that measured trait values of genotypes most closely reflect true values for the particular test environment. Field sites representative for the target cropping environment in terms of soil and climatic conditions, photoperiod, and pest and disease prevalence assure relevant selection conditions, but management to create environments differing from the natural one at any location can be useful (e.g., manipulating water supply). Maximum uniformity of growing conditions within any given test is a prerequisite to compare genotypes. Both natural (e.g., soil, topography, disease) and careless management can disrupt uniformity. Along with appropriate blocking of plots in replicated trials, careful agronomic management of breeding trials, including the setting of appropriate levels across all input levels can reduce variability of crop performance from natural causes. Spatially uniform management of input applications, and meticulous operation and checking of plot seeders and harvesters are essential for maximizing uniformity and accuracy. Usually plot border rows are harvested with the rest of the plot for yield, but overlooked is the bias created by both the extra (unnatural) space of the lateral path that border rows have and/or the competition between adjacent plots for the resources of this space. Even seeding depths and densities, and plot spacing and end-trimming are critical and can be assured by properly calibrated machinery. Plot combines equipped with grain cleaners, on-board weighing systems and sensors to measure grain humidity greatly facilitate data collection and accuracy, but must be regularly checked and calibrated.

15.6   Key Concepts

Good planning, knowledge of field site conditions and appropriate agronomic management reduce the experimental error, mimicking the target environment precisely is important to develop adapted varieties.

15.7   Review Questions

1. What is experimental error?
2. Why is agronomic management important in breeding trials?
3. How can agronomic management be used to reduce experimental error?
4. Why are field trials important when a wide variety of molecular genetic tools is available?
5. How can mechanization facilitate the implementation of breeding trials?

15.7.1   Review Question Answers

1. The experimental error is defined as the difference between a measured value of a quantity and its true value.
2. Good agronomic management creates selection conditions that lead to clear expression of trait differences between genotypes. It also reduces field variability which facilitates the detection of the best performing genotypes
3. Researchers should use agronomic management that maximizes the uniformity in the distribution of resources and results in vigorous crops. Researchers should carefully design and monitor field operations to minimize errors. Regular monitoring of the field is essential to ensure any problems with weeds, diseases or pests are caught early and can be managed before they introduce variability that affects the experiment. Variability in field operations like uneven applications of inputs should be prevented by regular revision and maintenance of machinery and equipment, providing detailed instructions and oversight for field operations.
4. Plants must perform under varying field conditions and complex traits like yield cannot be easily predicted. Ultimately, those data can only be obtained from practical experiments. Techniques, like genomic selection, require data from field experimentation, to predict performance of untested populations.
5. The use of adequate machinery like plot seeders and harvesters contributes to precise trial management and facilitates operation. Machine seeding assures even seeding depth and density. Plot combines can be equipped with grain cleaners, on-board weighing systems and sensors to measure grain humidity and weight, which can greatly facilitate data collection.

15.8 Conclusions

Agronomic management is very important in breeding programs to reduce the experimental error and create selection environments relevant for the target regions.

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