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A mobile and geo-referenced electromagnetic sensing system to assess soil salinization at spatial and temporal scales in irrigated fields

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Soil salinization has been identified by the European Commission as one of the eight major threats to European soils, mainly in the Mediterranean area. It reduces soil quality, limits the growing of crops and constrains agricultural productivity. The negative consequences are even worse for soils under irrigation, making their sustainability and economic and technical viability questionable. The mitigation and control of soil salinity is one of the main challenges in the agriculture of the 21^{st} Century. Meeting that challenge will require the efficient and accurate quantifying, inventorying, mapping, and monitoring of soil salinity. The traditional methods for determining soil salinity (the soil saturation-extract electrical conductivity-ECe) involve intensive field survey and laboratory analysis that are time-consuming and costly. The development of new technologies such as electromagnetic (EM) induction sensors has revolutionized the way in which soil salinity is measured. They measure the apparent soil electrical conductivity (ECa), which is closely related to soil salinity (ECe). To improve the efficiency of field measurements of ECa, EM sensors are combined with Global Positioning Systems (GPS) and incorporated onto vehicles. Mobilized EM sensors have been in use for over a decade, particularly in the United States and Australia. Those commercial mobile EM systems, however, are very expensive and complex for our agronomic conditions. In addition, considerable technological advances have been made in the last 10-15 years, so that new GPS models, software, etc. are available to be integrated into new mobilized EM systems. In this paper, a relatively simple and economical *Mobile Geo-referenced Electromagnetic Sensing System* (*MGESS*) developed at the Department of Agriculture of the Government of Navarre (Pamplona, Spain) is presented. A detailed description of the components and functioning of the MGESS

is provided. An evaluation of the usefulness of the new equipment to map soil salinity as compared to conventional methods is presented.

The MGESS consisted of (1) an electromagnetic EM38 sensor (Geonics Ltd, Canada) designed to measure salinity to a depth of 1 m or 2 m depending on whether it is held in the horizontal or vertical mode of operation, respectively, (2) a Global Positioning System (GPS) unit (Trimble *Pathfinder Pro-XT*) with differential correction, (3) a tablet PC for logging and integrating the incoming data into a single file, and (4) a simple non-metallic platform specifically developed to tow the EM38 sensor and the GPS antenna. The platform is attached to the vehicle through a 3 m long plastic tube to increase the distance between the EM38 and the vehicle, for eliminating the effects of the vehicle engine noise. The GPS antennae located above the EM38 sensor provides the coordinates of each measurement point.

The MGESS is pulled out by a vehicle with a traveling speed of 5-10 km h^{-1}. Electromagnetic (EM) measurements are taken in a fully automated on-the-go mode. The tablet PC, mounted in front of the vehicle operator, controls the data acquisition by logging GPS and EM instruments at given times using the GPS software (TerraSync™, Trimble ®).

The set-up of the MGESS was performed in a 23-ha salt-affected field located in the “Hondo de Espartosa” irrigation district, in Villafranca (Navarra, Spain). Location and ECa data were collected on 1-s intervals at a speed of 7 km h^{-1} in a grid of 18 x 2 m.

The MGESS allows automated measurements over large surfaces without a pre-established survey grid. Traversing the entire 23-ha-field using the mobile system required about 2 hours, and 6242 geo-referenced EM38 readings were recorded. Covering the entire field with the EM38 pedestrian system to get the same resolution would have required more than 60 hours.

The ECa map (obtained from the interpolation of the 6242 EMh readings) provided a rapid, easy and inexpensive means of determining the spatial distribution of soil salinity. It delimited areas with different levels of soil salinity, which was used to select suitable calibration sites to produce linear regressions between ECa and ECe. It should be emphasized that using classical soil survey methodology the resolution of the resulting soil salinity map would have been orders of magnitude lower. On the other hand, using manual collection of EM38 data, the time required to obtain the same resolution would have been much greater.

Geo-referencing and automation of soil ECa data collection through the MGES system significantly improves the efficiency of characterizing and mapping the spatial and temporal variability of salinity at field scales and larger.