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An implication of Fuzzy ANOVA: Metal uptake and transport by corn grown on a contaminated soil

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ABSTRACT

Three organic fertilizers of manure sheep, sewage sludge and municipal waste were mixed with soil at the rates of 0%, 1.25% and 2.5% (w/w), respectively. In a greenhouse experiment, corn seed were grown on pots of 3 kg treated contaminated soils and irrigated. Sixty days after sowing, the aerial plant parts were harvested and analyzed for Cadmium (Cd) and Lead (Pb) contents. Since all of data in this research are fuzzy, we need an extended version of analysis of variance (ANOVA) to investigate on these fuzzy observations. In this paper, as a method to compare several populations, the fuzzy analysis of variance (FANOVA) has been used where the collected data considered fuzzy rather than crisp numbers and therefore all calculations are based on FANOVA method. Although, ANOVA based on vague data can lead to a fuzzy decision, but measuring the vagueness of this fuzzy decision is one of advantages of proposed method from the applied point of view.

1. Introduction and background

Soil organic matters have always been considered in the research of nutrient absorption by plants. These materials can impact on nutrient concentration and absorption by plants directly or indirectly. This is due to the effect of organic matters on cation exchange capacity and metallic cation replacement and exchange in the form of stable complexes with organic ligand. Therefore, knowledge about the mechanism and extent of the effect of organic substances in the absorption and micronutrients concentrations can be used and is required for effective use of these materials as soil amendments. Nevertheless, land disposal of organic matters may either directly or indirectly alter the heavy metal status of the soil by dissociation kinetics or affecting metal solubility [7]. Soil pollution is becoming harmful to environment and human health. Heavy metals are among the most important elements of soil pollution and the environment which has attracted much attention among the researchers. Some of heavy metals are include Cadmium (Cd), Zinc (Zn), Copper (Cu), Lead (Pb), Nickel (Ni), Chromium (Cr) and Arsenic (Ar). Most heavy metals infiltrate and accumulate in the top of soil. Accumulation of heavy metals in soil is incremental and therefore in the long term results are increased the levels of contamination, so that it may reach limits that can constitute a real threat to food safety for human civilization [2,29].

A review of the investigation results shows that the heavy metals concentrations depend upon and varies with the metal type, soil condition and type of plant variety, but normally the levels of concentration in aerial parts of a plant or crop is significantly higher than other parts and significantly lower in seeds [12,16]. Sappin-Didier et al. [33] worked on Cd absorption capacity of transgenic tobaccos (Nicotiniana tabacum). Moreover, some plants species are characterized by a lower or higher tendency to absorb trace metal [24]. For example, Menon et al. [25] studied on Cd influence in Norway spruce (Picea abies), poplar (Populus tremula), willow (Salix viminalis) and birch (Betula pendula) trees and a variety of herbaceous under storey plants for three years. Root growth and evapotranspiration were decreased in metal polluted treatments, independent of the type of subsoil. Göthberg et al. [14] recorded Cadmium content in aerial and bellow spinach (Ipomoea aquatic) parts. Cao et al. [3] analyzed the potential ecological risk of Cd, Pb and Ar in agricultural black soil on both roots and shoots growth in soybean, and they showed that soil contamination from Pb contamination for almost all sampling sites had moderate ecological risk; Cd in some samples had high potential ecological risk; while soil contamination from Ar had low ecological risk. McBride [22] reported that the mobility of heavy metal was most nearly associated with soil pH and metal-organic complexation. McGrath et al. [23] indicated the addition of organic fertilizer decreases solution Cd and Ni concentrations, but increases the Zn extractability.

Environmental analyses are usually plagued by uncertainties in

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data, fuzziness in assumptions and imprecision in available modelling tools. These limits affect policy decisions and so must be communicated and quantified during the process of decision making. Therefore, the researcher may be confronted with uncertainties which are available as linguistics expressions and could be modelled by fuzzy numbers in some applied cases. For the last decades, investigation and research have been developed such that a coalition of fuzzy sets theory and statistics has been established with the bellow purposes [4]:

(i) *to introduce new data analysis problems in which the major target involves either using fuzzy terms or using fuzzy relationships;*
(ii) *to find out well-formalized models for elements combining fuzziness and randomness;*
(iii) *to develop statistical methods to handle fuzzy observations or imprecise data; and*
(iv) *to incorporate fuzzy sets to help solving conventional and classical statistical problems with crisp or precise data.*

Recently studies shows that the observations that are including vagueness can be analyzed by using the fuzzy set theory (FST). In other words, the vagueness which is included in data can be defined exactly by using a membership function of the FST, and therefore, the vague data can be figured by the membership functions. Such vague data is processed directly by the aid of the membership function in the statistical processes. The calculation process becomes more complicated with respected to the classical statistical process [20], because it is necessary to perform the calculation precisely using the membership functions. In many environmental and applied sciences such as social sciences, geology, economics and agriculture, there are several real-life populations where imprecise values can be assigned to their experimental outcomes. In this way, the FST is a suitable model to handle and formulize these populations in real cases, which is the reason of our need to the FST in the analysis of variance (ANOVA). In recent years, some papers [5,6,11,13,20,26–28,40] on different areas of ANOVA have been published based on the FST. See [36], for more details. These areas are as follows: investigating on the behavior of one-way fuzzy analysis of variance (FANOVA) and comparing it with regression model [6], exact one-way ANOVA testing under normal fuzzy random variables [27], bootstrap method for approximating the asymptotic one-sample tests by fuzzy random variables [26], developing a one-way ANOVA approach for the functional data on a given Hilbert space [5], processing ANOVA method using the moment correction for vague data [20], bootstrap asymptotic multi sample testing of means assuming fuzzy random variables [11,13], considering the cuts of fuzzy random variables for one-way ANOVA problem on the basis of fuzzy data based on optimization approach [40], and extending one-way ANOVA for fuzzy observations based on extension principle approach [28].

In this paper, the mean absorption of Cadmium and Lead in aerial and bellow corn parts to conclude whether it is dependent on the added levels of organic fertilizers have been analyzed. So, this research aimed to create a link between environmental practice and theoretical analysis of variance.

The rest of this paper is organized as follows: After introducing fuzzy numbers, arithmetic operations on triangular fuzzy numbers (TFN) have been summarized into Section 2. A new approach based of fuzzy measurements to analysis of variance as an alternative of ANOVA method has been detailed into Section 3. Section 4 includes an experimental study on Cd absorption based on a real-world agricultural data (generated in a Lab. at Tehran University by Ivani [15]) presented. The obtained results and future research directions for the proposed fuzzy ANOVA method have been discussed in Section 5, Conclusions.

2. Fuzzy sets and arithmetic operations on fuzzy numbers

2.1. Fuzzy set theory

The fuzzy set theory (FST) models the situations in which the uncertainty is due to the non-precise (fuzzy) environment. A method to handle practical problems, particularly those connected with vagueness and uncertainty about input values and theoretical relationships is using the proposed FST theory proposed by Zadeh [41]. A usual crisp set has a clearly defined boundary, such as any real number which is either a member of a crisp set or it is not. But a fuzzy set is a set without a crisp boundary and it can contain elements with degree of membership as a number between 0 and 1. Using the FST is inevitable with the situations such as uncertain, imprecise or the cases that include linguistic expressions. Fuzzy logic is a branch of mathematics that allows a computer to model the real world in the same way that people do. It provides a simple way to reason with vague, ambiguous, and imprecise input or knowledge [9,17–19,35].

For example, suppose one define the optimum range of Zn absorption in a plant as the interval [15,150] mg kg^{-1}.D.M. Using traditional set theory, it is possible to define the equilibrium absorption amount as a crisp value set containing the element 25 mg kg^{-1}.D.M. In this case, a crisp set considered and any given absorption amount is either in or not in the equilibrium range. But in contrast, fuzzy sets allow for partial membership and an absorption amount 25 mg kg^{-1}.D.M might regarded as having partial membership of equilibrium set and partial membership of a below-equilibrium set. This flexibility allows users to deal with uncertainty and imprecision which is in the nature of many real world problems [34,36]. See Parchami et al. [30] for a similar implication of testing fuzzy hypotheses based on a real-world data. In the following we will discuss and review some of the mathematics of the FST.

2.2. Fuzzy data: why and where?

Real observations for the quantities of continuous variables are not precise numbers and they are more or less imprecise [37]. The best description of such observations is using an especial numbers which called imprecise (fuzzy) numbers. In real world, the fuzziness of an observed continuous variable often happens in one of three following cases:

(i) The first case is because of technical conditions of measurements where the continuous variable cannot measured exactly and so in this case, the results of experiments cannot recorded clearly with precise numbers and only in linguistic terms to justify the required tolerance of the errors in measurements. In other words, the experimenter has not a capable instrument to measure the exact value of the nature. For example, the data readings on analogue measurement equipment or the given data by color intensity pictures can considered as fuzzy numbers instead of precise numbers [10].
(ii) The second case is due to the fact the continues variable will be given by linguistic forms, such as linguistic report of an expert or the report of a farmer about his products, which are not numeric [28].
(iii) In the third case, the true value of continues quantity has not exactly a precise amount, and therefore the experimenter cannot be able to exactly record and present its value by precise numbers. For instance, the water level of a river cannot be measured in an exact way because of the fluctuation [18,40]. Another typical example for third case is the lifetime of a battery which cannot, in general, be described exactly by a real number since the time at which the lifetime ends is not a crisp number but is more or less imprecise.