International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

A Fuzzy Machine Learning Based Approach for Promoting Sustainability in Agriculture.

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Submitted: 11/12/2023 **Revised**: 17/01/2024 **Accepted**: 26/01/2024

Abstract: Agriculture being the backbone of India, various factors affect the sustainability of the food products and he farmers. Factors like soil, geographic region, and climatic parameters impact significantly on crop yield and productivity. The farmers in India follow the traditional approach for harvesting. This is due to the lack of awareness and not having adequate knowledge of the challenges the parameters have on crop products due to which it often leads to financial and social loss to the farmers. An approach is much required to provide an efficient solution to extend help and sustainability of the farmers. The current study recommends a fuzzy logic-based recommendation system for the cash crops to help the farmers have financial and social sustainability. The proposed recommendation system is designed using a Fuzzy Inference System (FIS) using the rule-based logic approach to achieve an accuracy of 93% which is examined and validated.

Keywords*: Agriculture, sustainability, recommendation system, expert system, Mamdani Fuzzy Inference System.*

1. Introduction

India being a developing country is globally acknowledged since years for the agricultural sector. The agriculture sector being one of the most significant economical contributors for the country is also the second-largest producer of crops likes rice, sugarcane, wheat, etc [1]. Agriculture in India is a subject of immense significance and scholarly exploration due to its multifaceted nature, historical roots, and contemporary relevance. India's agricultural heritage dates to the Neolithic era, making it one of the world's oldest farming civilizations. India's history is rich with diverse crops, traditional farming practices and approaches, and the profound influence of agriculture on society and culture as well [2]. Indian agriculture sector has always been a pivotal part as the backbone of the country's economy, where it is contributing significantly to the Gross Domestic Product (GDP) and helps to provide livelihoods to a major and substantial part of the Indian population, it plays a significant role in ensuring food safety, security and sustains various industries through the supply of raw materials. For a population of over 1.3 billion, agricultural sector of India is sustaining the requirement of the people of India, owing to which India ranks second worldwide in agricultural crop production. This sector not only provides livelihoods to a significant portion of the population but also serves as a critical source of food security, raw materials for industries, and foreign exchange earnings [3]. On the other hand, due to climatic diversification, climatic changes, soil erosion, decrease in soil fertility, it has these challenges which affect the crop productivity.

The sector is witnessing transformations with the adoption of modern technologies, precision farming, and sustainable practices. Expert systems, a sub-set of artificial intelligence (AI), have found significant application in various domains, including agriculture. These systems are computer programs de-signed to mimic the decision-making abilities of hu-man experts in specific fields. Expert systems are knowledge-based databases, from which we may rely for decision-making capabilities. The knowledge base is represented in the form of facts, figures, rules, and different heuristic approaches which is then being used by the system to analyses and provide a solution to the problem. These systems are particularly beneficial in complex agricultural scenarios and situations where human expertise is required [4]. Expert systems offer decision support and decision-making feasible to farmers and agricultural experts. They can assist in tasks such as crop management, pest control, irrigation, and disease diagnosis. By inputting data related to specific agricultural conditions, the system can generate recommendations and predictions, aiding in informed decision-making approaches. The expert systems serve as valuable training tools. which provides a structured way to convey agricultural knowledge to new generations of farmers and agricultural professionals. These systems facilitate learning by explaining the reasoning behind recommendations [5]. Expert systems can be adeptly tailored to match specific agricultural contexts and areas. This adaptability ensures that the recommendations provided are relevant and effective in addressing local challenges and conditions of the farmers both socially and

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economically. On the go, expert systems are core to the concept of precision agriculture and sustainability of food products [6]. They enable the precise application of resources like fertilizers and pesticides, optimizing yields while minimizing environmental impact. Artificial intelligence systems have demonstrated extensive utility across diverse domains, encompassing control systems, pat-tern recognition, decision-making processes, and the realm of artificial intelligence itself. These systems garner significant appreciation for their proficiency in adeptly managing intricate and indistinct datasets [7]. Fuzzy systems constitute computational models rooted in the domain of fuzzy logic, a meticulously devised mathematical framework crafted to adeptly address the intricacies of uncertainty and imprecision within data. In stark contrast to the binary rigidity of conventional true-or-false logic (characterized by the values 1 or 0), fuzzy systems fundamentally adhere to the principle of "degrees of truth." This paradigm allows variables to encompass values spanning the continuous spectrum between 0 and 1, thereby eloquently capturing the nuanced extent to which a given statement holds true [8]. Their pronounced efficacy becomes most apparent when confronted with scenarios or systems marked by inherent uncertainty or ambiguity, where the conventional precision of binary decision-making proves inadequately rigid. In essence, fuzzy systems represent a pivotal inter-section between mathematical rigor and the pragmatic accommodation of real-world complexity [9].

In this paper, a crop-recommendation system has been proposed which uses the climatic parameters as per the Agro-Climatic zones to promote the sustainability of farmers financially and socially. The state of Rajasthan is a case-study which is presented in the paper to select the profitable crops which will be economically viable for the farmers. Fuzzy logic-based systems have been designed by various researchers but using the agro-climatic parameters globally, suggesting the cash crops for the farmers is a novel approach to achieve agricultural sustainability [10]. Many researchers have suggested various methods of crop-recommendation using fuzzy inference system considering the local parameters, whereas the current work is not restricted locally rather, the climatic parameters of the global climatic factors are considered and according, the cash crops are recommended as per the agro-climatic zones of the state of Rajasthan. This will significantly help the farmers to improve their financial and social sustainability and stability in today's era.

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully, and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your field of research. References should be numbered in order of appearance and indicated by a numeral or numerals in square brackets, e.g., [1] or [2,3], or [4–6]. See the end of the document for further details on references.

2. Materials and Methods

In the current work, the state of Rajasthan has been chosen as the region of experiment and implementation. The state of Rajasthan is one of the largest states of Indian sub-continent and has a large agricultural land which is a good producer of maize, wheat, bajra, millets. The state is diverse in agro-climatic zones and for which it becomes an area for application of such system which benefits the farmers and the society.

2.1 Data Collection

Data collection is a significant step and a pivotal process which plays an important role in designing the systems which helps to improvise the agricultural practices. The dataset was collected over a span of three years from across the globe as per the agro-climatic conditions of the state of Rajasthan. There are a total of 10 zones which affect the climatic conditions of the state. The zones are Arid-western plain, Irrigated northwestern plain, Hyper-arid partial irrigated zone, Internal drainage dry zone, Transitional plain of Luni basin, Semi-arid eastern plains, Flood prone eastern plain, Sub-humid southern plains, Humid southern plains, Humid southeastern plain [11]. These zones have different climatic parameters hence, the crop harvesting, and crop pro-duction also diversifies as per the zones. The proposed system has included the zonal parameters and patterns to have a match it with the countries having similar climatic and environmental parameters. The features used for the Fuzzy inference system are rainfall (in mm), average temperature, Average wind Gust (in km/hr.). These data were collected from NASA weather forecasting site [12].

2.2 Data pre-processing

The dataset collected over a period of three years for various zones globally is pattern-matched with the agro-climatic zones of the state of Rajasthan. The dataset is to be treated to the fuzzy system as input dataset based upon which the fuzzy system will be able to recommend the cash crops for the zones of the state. The null values and missing values were taken care of by taking the mean value of the previous year data.

2.3 Design of the proposed Fuzzy Inference System

The fuzzy inference system has three phases of operation:

a fuzzification stage, an inference stage and defuzzification. Fuzzification stage includes the input stage of the crisp values and fuzzifying it with the various techniques to convert it to fuzzy set values [13,14]. The second stage determines the rule-base of the system depending upon which a decision can be made and as per the logic the rules can be fired. The last stage is the defuzzification stage where the fuzzified output must be converted to a defuzzied value as crisp value. The rule-base are the inference rules using the form of "IF THEN ELSE" where we use the linguistic variables to define the conditional approach of if-else. The fuzzy logic also includes the AND-OR operations which are useful when a system [15].

2.4 Membership Function and Input Parameters

The fuzzy inference system uses various member-ship functions to deduce the relationship of dependency. The fuzziness of the system is best characterized by its membership functions which represents the degree of truth which is represented using graphical forms. These graphical forms help to interpret the fuzzy set values for the inputs. Fuzzy logic has singleton, triangular, trapezoidal, gaussian, generalized bell-shape, sigmoidal. In the current study, triangular membership function (trimf) is chosen [16]. The mathematical equation for the triangular function is given as in equation 1.

$$\mu(x) = \begin{cases} 0 & \text{if } x \leq a \\ (x - a) / (b - a) & \text{if } a \leq x \leq b \\ (c - x) / (c - b) & \text{if } b \leq x \leq c \\ 0 & \text{if } x \geq c \end{cases} \quad (1)$$

The trimf function is the most common and easy to implement, also or the current dataset in the study, triangular membership helps to achieve better results. Each of the features for the inputs are expressed in linguistic variables as in Table 1.

Table 1. Describing the input parameters with linguistic variables and the ranges used in the Fuzzy Inference System

Input parameters	Linguistic Variables	Ranges
Average Temperature(ºC)	Temperature	9.7-44.5
Rainfall (in mm)	Rainfall	40-2300
Humidity	Humidity	14-96
Average Wind Gust (in k/hr)	Wind	8-34

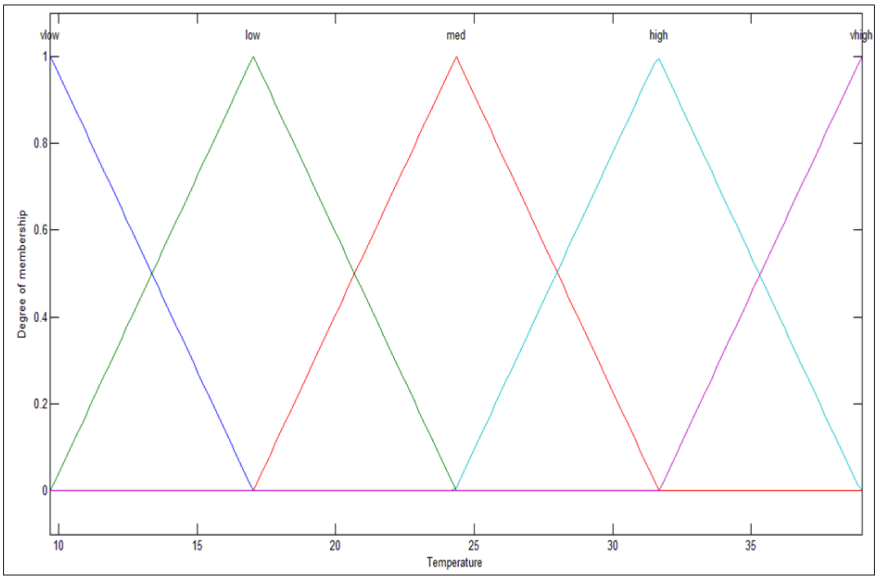

Fig 1. Describing the Input parameter Temperature with linguistic variables.

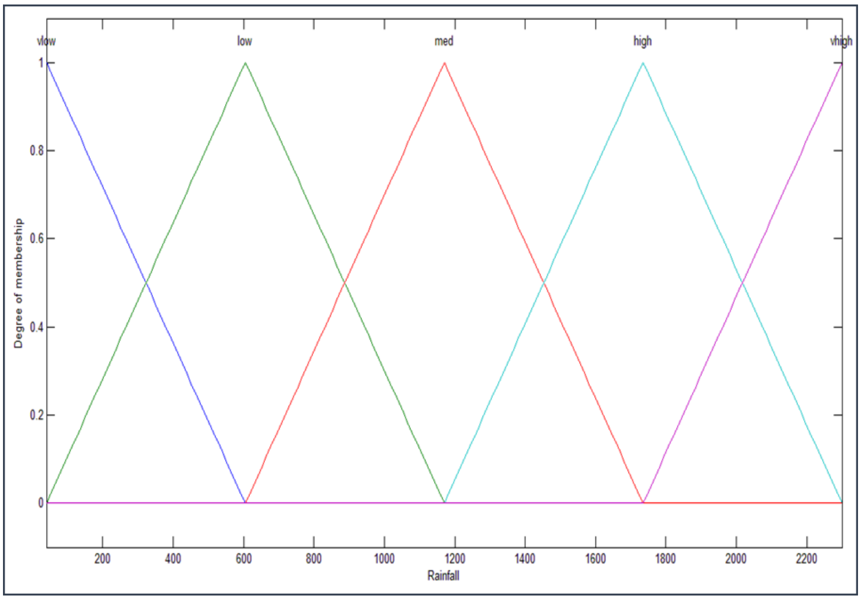

Fig 2. Describing the Input parameter Rainfall with linguistic variables

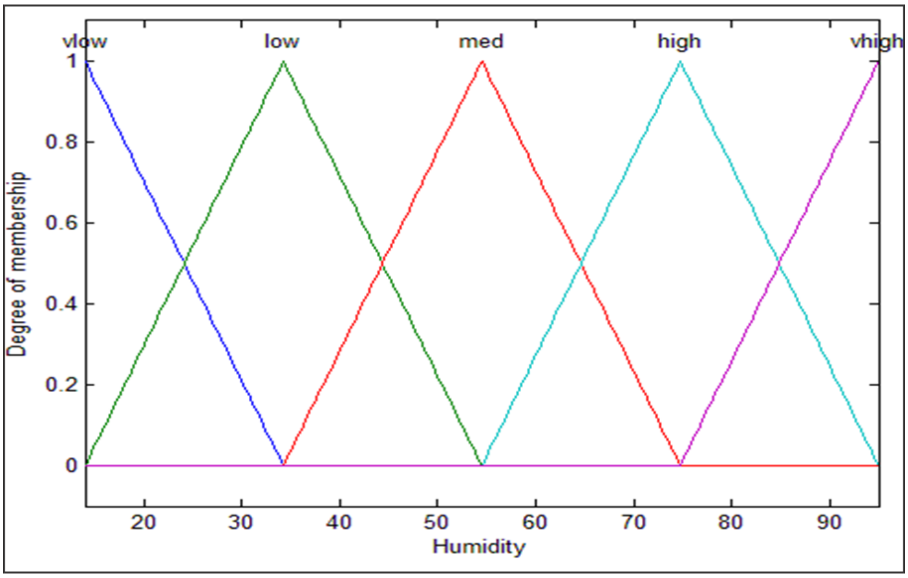

Fig 3. Describing the Input parameter Humidity with linguistic variables

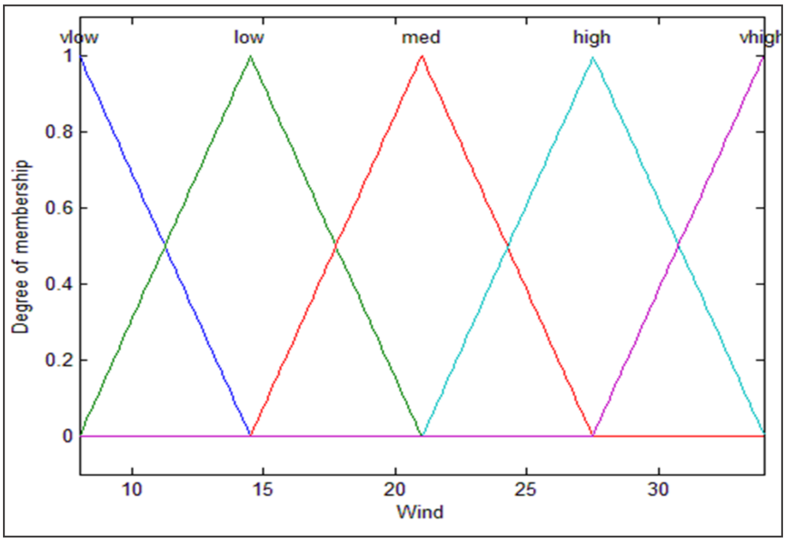

Fig. 4. Describing the Input parameter Wind with linguistic variables

2.5 Output Parameter

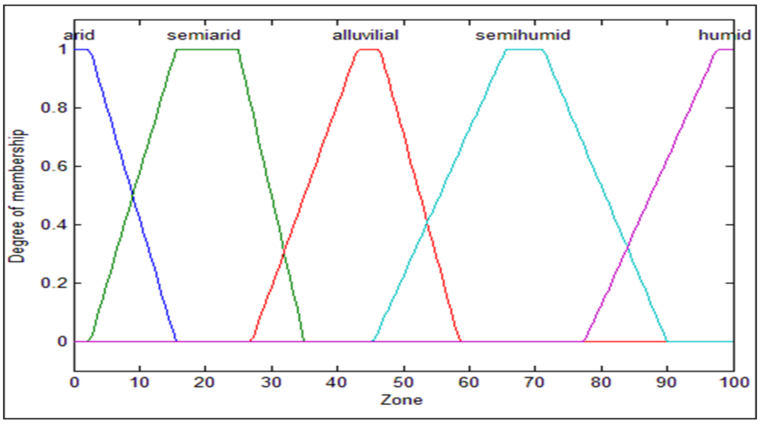

Fig 5. Membership Function for output parameter "Zone" with the linguistic variables

The output parameter chosen is agro-climatic zone to which the global patterns fall into such that, accordingly, the system can recommend the cash crops for the farmers. Figure 5 shows the membership ranges for zone. The linguistic variables used for the output feature zone are arid, semiarid, alluvial, semi humid, and humid.

2.6 Fuzzy Inference System

Once the membership functions and ranges are designed, the rule-base for the input parameters with the output parameters are to be formed to generate the fuzzy value depending upon the rule-base. The output parameter zone was recommended as per the IF-THEN rules. The inference system used for the current study is Mamdani Inference System [10,4]. Mamdani approach is a fundamental part of fuzzy system that plays a significant role in decision-making process. This approach is simple and is most widely used to treat uncertainty and imprecision. This approach is based upon the set of linguistic variables and the IF—THEN rule. These rules define the dependency between the input parameters to the output. The approach is categorized as Type-1 and Type-2 systems depending on the complexity of the fuzzy dataset used.

2.7 Defuzzification

This step includes the last phase of fuzzy inference system which converts the fuzzy output of the inference system to the crisp, numerical value which helps used for making decisions. There are various approaches or methods used for defuzzification like centroid method, bisector method, mean of maxima method, weighted average method, weighted sum method, centre of area method, In the current study, the output Zone obtained from the inference system was defuzzied using the centroid method to obtain the final crisp output recommended as per the input parameters.

3. Case Illustration

To understand the method of implementation, a case study is illustrated. For a case, the input features obtained were X= {Temperature=24.4, Rainfall=1170, Humidity=67.5, Wind=21} after the normalization the zone it falls is 'Alluvilial' with value as 32.4. A total of 625 rules were designed to implement the fuzzy inference system. The rules that were designed for the input parameters are:

Rule 1:

If Temperature is vhigh AND Rainfall is vhigh AND Humidity is vhigh AND Wind is vhigh then Zone is humid.

Rule 2:

If Temperature is vhigh AND Rainfall is vhigh AND Humidity is vhigh AND Wind is high then Zone is humid.

Rule 3:

If Temperature is vhigh AND Rainfall is vhigh AND Humidity is vhigh AND Wind is med then Zone is alluvilial.

Rule 4:

If Temperature is vhigh AND Rainfall is vhigh AND Humidity is vhigh AND Wind is low then Zone is humid.

Rule 5:

If Temperature is vhigh AND Rainfall is vhigh AND Humidity is vhigh AND Wind is vlow then Zone is humid.

Similarly, there were 625 rules designed for the system. The above rule is a sample rule from the 625 rules designed in the proposed system. The rule used to describe the output parameter of zonal entries is:

If Temperature is medium AND Rainfall is medium AND Humidity high AND Wind med THEN Zone is Alluvial.

4. Results and Discussion

The Fuzzy Inference System used in the current study was constructed and designed using the soft-ware MATLAB R2018a Fuzzy Logic Designer Toolbox. Mamdani Fuzzy Inference System was used in the current paper. The IF…THEN rule-base used had a total of 625 rules with four input parameters as temperature, rainfall, humidity, and wind and one output as Zone. The system was tested with 85 real time filed cases for the state of Rajasthan. The cash crops feasible in the zones as recommended by the fuzzy system used in the current study. Nowadays, it's the requirement to maintain sustainability of the farmers in the current global region as well. The figures 6 and 7 describes the surface plots between the input parameters to the output parameters for a better understanding of the significance of dependency if input to output through the membership values whereas table 2 infers the recommendations made by the fuzzy inference system for the various zones with an average accuracy of 93.82 %.

Table 2. Result summary for the system

Zone	Linguistic variable	Correct recommendations	Improvised recommendations	Accuracy (in %)
Arid	arid	86	5	88.3
Semi-Arid	semiarid	93	8	94.23
Alluvial	alluvilal	98	18	96.56
Semi-Humid	semihumid	75	10	92.37
Humid	humid	88	2	97.65
Average				93.82

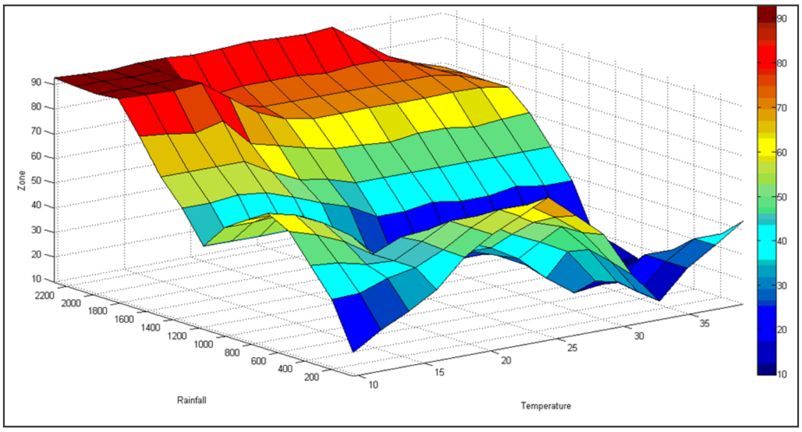

Fig. 6. Surface plot between Temperature and Rainfall

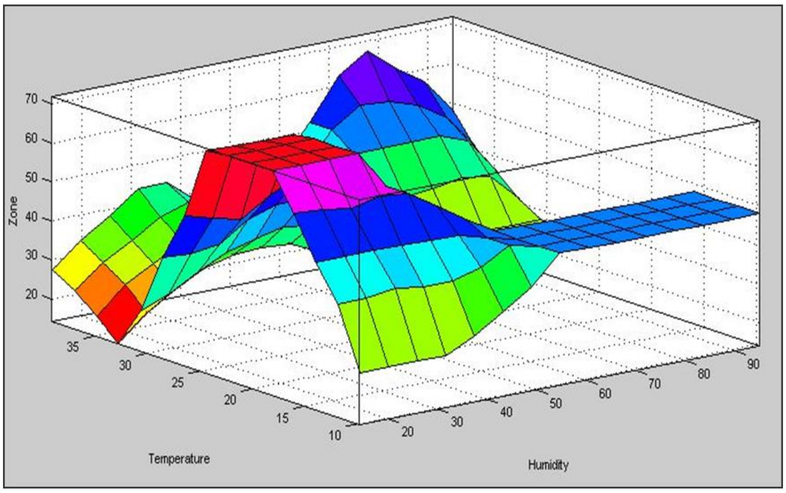

Fig 7. Describing the Input parameter Temperature with linguistic variables.

5. Conclusions

The current study is a process and attempt to design an efficient and hybrid recommender system to recommend zones and as per which the cash crops can be harvested considering the various climatic parameters like temperature, rainfall, humidity, and wind using the fuzzy logic and fuzzy rules for the state of Rajasthan. The dataset contained four input parameters and corresponding zone were identified with the proposed model. The linguistic variables and membership values were derived from the dataset for the input and output parameters. The performance of the model was tested and validated for different cases. The accuracy of the model was obtained to be 93.82%. There is no similar system with the novel approach of using similar agro-climatic zones for the cash crop harvesting's model and approach will help the farmers to make efficient decisions in selecting the crops for their financial gain nationally and internationally. The above solution presented in the current study will promote agricultural sustainability thereby helping the farmers to have financial gains.

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