Productivity, nutrient use efficiency, energetics and bio-economics of winter maize in south India

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Research Article

Keywords: Bio-economics, energetic, fertility, grain, planting, RDF, winter maize, yield

Posted Date: April 2nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-364825/v1

Productivity, nutrient use efficiency, energetics and bio-economics of winter maize in south India

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Abstract: Maize area is rapidly spreading in south India in response to rising demand from the poultry and fish feed industries. The planting of maize during winter season is necessary to increase the total area and production of maize. The present investigation encompassing different sowing windows with different fertility levels revealed that significantly higher winter maize productivity was achieved from first and second week of October planting along with application of 200 % RDF(recommended dose of fertilizer) followed by 150 % RDF. Planting of winter maize during first week of October recorded significantly higher grain yield (8786 kg ha^{-1}) and stover yield (1220 kg ha^{-1}) and was found on par with sowing during second week of October. Among fertility levels, significantly higher grain yield (8320 kg ha^{-1}) and stover yield (1195 kg ha^{-1}) were recorded with application of 200 % RDF and was found on par with application of 150 % RDF. Similarly higher dry matter production, more days for physiological maturity, higher accumulation of growing degree days, photo thermal units and heliothermal units were recorded from crop planted during first and second week of October along with application of either 200 % or 150 % RDF. Further higher nutrient use efficiency was recorded from first and second week October planted crop along with lower fertility level (100 % RDF). Similarly significantly higher output energy, net energy and specific energy were higher from crop planted during first week of planting along with application of 200 % RDF. Also it recorded higher net returns and gross returns Whereas, energy use efficiency and energy productivity were higher with planting during first week of October along with application of 100 % RDF.

Keywords: Bio-economics, energetic, fertility, grain, planting, RDF, winter maize, yield

Introduction

The world's maize area is 192.50 million hectares, and it ranks first in production with 1,112.40 million metric tonnes. The leading producers are USA (32.61 %), followed by China (22.91%), Brazil (9.42 %), European Union (8.41 %), Argentina (5.41 %) and India (4.1 %)[1]. After rice and wheat, it is India's third most popular crop. It is currently grown on 9.38 million hectares with a yield of 28.752 million metric tons[2].Because of its photo-thermo-insensitive nature and highest genetic yield potential among cereals, maize is known as the "Queen of Cereals." . Corn is grown all year round in India, in most states, for a variety of purposes including food, feed, fodder, green cobs, sweet corn, baby corn, pop corn, and industrial goods.There are three distinct seasons for the cultivation of maize in India *viz., Kharif, rabi* in peninsular India and Bihar, and spring in northern India. Maize is predominantly a *kharif* season crop but in past few years winter maize has gained a significant place in total maize production in India[3]. Winter maize is grown on an area of 1.697 m ha with a production of 8.302 million metric tons and with a productivity of 4893 kg ha^{-1} [4]. The predominant winter maize growing states are Bihar (26.3 %), Tamil Nadu (13.1 %), Maharashtra (12.9 %), West Bengal (12.4 %), Andra Pradesh (9.5 %), Telangana (6.9 %) and Karnataka (6.4 %)[4]. It has emerged as an important crop in the non- traditional areas. While the crop responds favorably to better crop management in both the *kharif* and winter seasons, the irregular rainfall pattern of the south-west monsoon interferes with timely field operations of the *kharif* season. Due to the lack of significant environmental impediments in winter, the desired field operations can be scheduled and carried out at the most suitable time. In addition, lack of any major diseases and insect pests in this season, are helping the crop to express its potential. There is therefore an enormous opportunity to increase the area under cultivation of winter maize for higher productivity[3].

For winter maize, the best sowing date is essential so that the genotype grown can complete its life cycle under ideal environmental conditions. Planting at the beginning of the growing season is generally recommended. Sowing at the right time is critical for maximum yield, as a delay in the planting date would result in a linear decrease in grain and stover yields[5]. The amount of yield reduction caused by delayed sowing, on the other hand, varies by location. Hence experiment was conducted to explore the most congenial sowing period in Southern India.

The availability of sufficient nutrient in the soil in available form for plant uptake determines crop plant growth and yield[6]. There are a several of other factors that influence winter maize production and productivity; however, fertiliser management is one of the most important factors influencing maize growth and yields. Early maize planting can improve grain yields significantly, but other practises such as fertility can also trigger the yield[7].

In agriculture, energy usage has intensified as a result of increasing population, a limited supply of arable land, and a demand for a higher standard of living[8]. It is critical to create a production system that uses less energy and produces more energy as output in the context of changing global climatic conditions and increasing energy demands[9]. In this experiment, all of the inputs and outputs were considered to be in the form of energy. Human labour, animal power, fertiliser, gasoline, and electricity are all used in some way in agricultural operations[10].All the inputs supplied and output obtained is considered in the form of energy. Power, electricity, machinery, seeds, fertilisers, and chemicals account for a significant portion of the existing agricultural production system's energy supply. One of them is fertiliser control with care. Since, on the one hand, it accounts for more than half of the total input energy used in the maize production system in many cases, and on the other hand, it is the most important factor for proper plant growth and development. However, if it is used excessively in such cases, it can pollute rivers and streams, as well as cause greenhouse gas emissions. As a result, excessive deployment, wastes resources and money while also exacerbating environmental problems[11]. Fertilizers, with a energy equivalency of 51.5 percent, were found to have the highest rate of energy equivalency among all the inputs used in maize production[12]

Planting window is one of the non-monetary input. Planting a crop at the right time increases not only the biological yield but also the profitability. It is important to investigate the required level of fertility and planting window in order to achieve long-term sustainability in winter maize production

Material and Methods

Experimental site

During the winter season 2019-2020, a field experiment was conducted to investigate the response of winter maize to planting windows and fertility levels at the University of Agricultural Sciences, Dharwad (Karnataka), which is located at 15°26' N latitude and 75°07' E longitude with an altitude of 678 m above mean sea level (MSL). The research station is located in the Northern Transitional Zone (Zone-8), which is located halfway between the Western Hilly Zone (Zone-9) and the Northern Dry Zone (Zone-9) (Zone-3). The soil is classified as clay by the USDA soil textural classification table. The pH of the soil was 7.6, which was neutral. Available nutrients such as nitrogen were low (261 kg ha-1) and phosphorous (31.5 kg ha-1) and potassium (289 kg ha-1) were medium.

Treatment details

The experiment was conducted in a Factorial Randomized Complete Block Design (RCBD) with three replications and fifteen treatment combinations. Planting windows (1st week of October, 2nd week of October, 3rd week of October, 4th week of October, and 5th week of October) and fertility levels (100 percent recommended dose of fertiliser (RDF), 150 percent RDF, and 200 percent RDF) were used as factors in the experiment. The single cross maize hybrid used was Monsanto's 900 M Gold.

It is popular private sector hybrid legally available in the public domain as well as at Dept. of Agriculture Govt. of Karnataka for commercial maize cultivation. It is one of popular hybrid among the maize growing farmers and has been taken for agronomic experiment for optimizing planting dates and fertility in winter season of south India. Hence it comply with relevant institutional and national guidelines.

Monsanto India Pvt. Ltd. released 900-M Gold (Mon-26) maize hybrid and it is in public domain for cultivation as well as agronomic research on maize as it is registered in India vide notification no.2137(E) in INIDA GAZETTE dated 31-08-2010. Further it is in the list of maize cultivars released for cultivation in India during 2010. Since its release it is being used for commercial cultivation as well as agronomic research in India. Hence this material has been deposited at NBPGR, New Delhi, India.

Cultivation method

To bring the soil to fine tilth, the field was ploughed once, followed by tillage with a cultivator and harrowed twice. After the previous crop was harvested, weeds and remaining residues were removed from the experimental field. The plots were set out according to the experiment's layout design. Seeds were planted at a 60 cm x 20 cm spacing with a seed rate of 20 kg ha-1. With the aid of a marker, the lines were opened, and the seeds were hand-dibbled at a depth of 4-5 cm before being covered with soil. All other treatment plots, including control plots, had well decomposed FYM @ 10 t ha^{-1} incorporated into soil two weeks prior to planting.The nutrients *viz.,* nitrogen, phosphorus and potassium were applied @ 150 kg N ha^{-1}, 65 kg P_2O_5 ha^{-1} and 65 kg K_2O ha^{-1} for fertility level of 100 % RDF. Similarly for 150 % RDF, 225 kg N , 97.5 kg P_2O_5 and 97.5 kg K_2O ha^{-1} was applied. And for 200 % RDF, 300 kg N, 130 kg P_2O_5 and 130 kg K_2O ha^{-1} was applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP) respectively. $FeSO_4$ and $ZnSO_4$ were applied @ of 25 kg ha^{-1}.First intercultivation was done at 30 days after planting. Hand weeding was done at 30 and 55 days after planting to check the weed growth and to keep the plots free from weeds during the cropping period in all the dates of planting. With a spray of proclaim @ of 0.5 g litre-1, the crop was protected against fall army worm and stem borer. For all planting dates, the rainfall obtained during respective planting windows provided ample soil moisture for germination, emergence, and early establishment of seedlings. Rainfall fell during the crop growth cycle in the months of October (323.2 mm) and November (21.0 mm), and the rest of the season's crop was irrigated using the critical stage method. Since the experiment was conducted entirely under irrigated conditions, the crop did not experience moisture stress during the growing season.

Growth parameters related to weather

Growing degree day (GDD)

Growing days were determined in this study by simply adding up daily mean air temperatures above a given threshold or base temperature. It can be expressed mathematically as follows:

$$GDD\ (℃\ day) = \frac{T_{max} + T_{min}}{2} - T_b$$

Where,

T_{max} - Maximum temperature (°C)

T_{min} - Minimum temperature (°C)

T_b - Base temperature 10 °C (Narcico *et al.*[13])

Photothermal units (PTU)

The photothermal units for a specific day represent the product of GDD and length of the day. Photo thermal units were calculated by using the equation given by Wilsie[14].

PTU (°C day hr) = GDD X L

Where, GDD – Growing degree days (°C day)

L – Day length (hrs)

Heliothermal Units (HTU)

The heliothermal units for a specific day are the product of multiplying GDD by the number of hours of bright sun that day. The tape in the Campbell-Stroke sunshine recorder burns when the strength of sunlight reaches a pre-determined threshold. The burn trace's total duration is equal to the amount of bright sunlight hours15. The formula was used to measure the total HTU for each phenophase's length

Accumulated HTU (°C day hr) = GDD × Bright sunshine hours (hrs)

Nutrient use efficiency

The sum of product produced per unit of resource used is referred to as NUE. The amount of dry matter generated per unit of nutrient applied or absorbed is the mean nutrient efficiency. NUE is the difference between a genotype's yield on deficient soil and its yield at optimum nutrition[16.] Agronomic efficiency,

physiological efficiency, and recover efficiency[17] are the three types of nutrient efficiency.

The agronomic efficiency (AE) is defined as the economic production obtained per unit of nutrient applied. It can be calculated with the help of following equation.

$$AE\ (kg\ kg^{-1}) = \frac{\text{Grain yield of fertilized crop (kg)} - \text{Grain yield unfertilized crop (kg)}}{\text{Quantity of nutrient applied (kg)}}$$

Sometimes, AE is also called as economic efficiency.

Physiological efficiency (PE) indicates grain yield increase in kg per kg nutrient uptake from fertilizer[18]. Expressed in kilogram per hectare (kg ha^{-1}).

$$PE\ (kg\ ha^{-1}) = \frac{\text{Grain yield of F plot} - \text{Grain yield of A plot}}{\text{Nutrient uptake of the F plot} - \text{Nutrient uptake of the A plot}}$$

Recovery efficiency (RE) is the quantity of nutrient taken up by the crop to the per unit of nutrient applied[18] and expressed as percentage.

$$RE\ (\%) = \frac{\text{Nutrient uptake of the F plot} - \text{Nutrient uptake of the A plot}}{\text{Quantity of nutrient applied}} \times 100$$

Bio-economics

The price in USD of the inputs prevailed at the time of their use was considered for working out the cost of cultivation per hectare treatment wise and expressed in USD ha^{-1}. A gross return per hectare was calculated by taking into consideration of the price of the product that prevailed in market after harvest and grain yield per hectare and expressed in USD per hectare (USD ha^{-1}). The net return per hectare was calculated treatment wise by subtracting the total cost of cultivation from gross return and expressed in USD per hectare (USD ha^{-1}).

Net return (USD ha^{-1}) = Gross return (USD ha^{-1}) – Cost of cultivation (USD ha^{-1})

The benefit cost ratio was calculated as follows.

$$\text{Benefit cost ratio (B-C)} = \frac{\text{Gross return (USD ha}^{-1}\text{)}}{\text{Cost of cultivation (USD ha}^{-1}\text{)}}$$

Note- Indian rupee was converted using a 70 INR for 1 USD rate.

Energetics

All the agricultural inputs such as seeds, fertilizers, labour, animals, electricity, machinery, organic manures *etc.* and all the agricultural outputs such as grain and straw have their own equivalent energy (Mega Joules) values (Table 1). The energy balance was calculated using the data on input energy, output energy. From these, the net energy returns, energy use efficiency, energy productivity and specific energy were calculated using the following formulae[19-23].

Net energy (MJ ha^{-1}) = Total output energy (MJ ha^{-1}) – Total input energy (MJ ha^{-1})

$$\text{Energy use efficiency} = \frac{\text{Total output energy (MJ ha}^{-1}\text{)}}{\text{Total input energy (MJ ha}^{-1}\text{)}}$$

$$\text{Energy productivity (kg MJ}^{-1}\text{)} = \frac{\text{Maize grain yield (kg ha}^{-1}\text{)}}{\text{Total input energy (MJ ha}^{-1}\text{)}}$$

$$\text{Specific energy (MJ kg}^{-1}\text{)} = \frac{\text{Total input energy (MJ ha}^{-1}\text{)}}{\text{Maize grain yield (kg ha}^{-1}\text{)}}$$

Statistical analysis and the interpretation of data

Fisher's method of analysis of variance, as outlined by Gomez and Gomez36, was used to statistically analyse the data collected at various stages of crop development. The data was analysed with the MSTAT-C statistical programme, and the means were compared using the Duncan Multiple Range Test (DMRT) at a 5% level of significance. The highest values were denoted by the letter ‘a,' which was followed by

the alphabets for lower values (b, c, d etc.). At the 0.05 level of significance, values denoted by the same small letter in the column do not vary significantly.

Results

Weather, GDD, PTU, HTU and days for physiological maturity

During the winter cropping season (2019-2020), a total rainfall of 352.0 mm was received out of which 323.2 mm was received during the planting month (October) (Fig.4). The highest and the lowest maximum temperature were 31.8 ºC (February) and 28.5 ºC (December), respectively, while the respective highest and the lowest minimum temperature were 15.5 ºC (January) and 20.3 ºC (October) respectively were recorded during cropping period. The mean relative humidity ranged from 49.4 per cent in February to 79.8 per cent.

The accumulated GDD, PTU and HTU were significantly differed due to planting windows (**Table 2**). Planting during 1st week of October recorded significantly higher GDD, PTU and HTU accumulation (1530.1 ^{0}C day, 17371.3 ^{0}C day hr and 11758.5 ^{0}C day hr respectively) and further it took significantly more number of days for physiological maturity (120.0 days). However, it was on par with planting during 2nd week of October (116.1 days). Similarly among the fertility levels, 200 % RDF recorded significantly higher accumulated GDD, PTU and HTU (1493.5 ^{0}C day, 17026.7 ^{0}C day hr and 12077.5 ^{0}C day hr respectively) and application of 200 % RDF took significantly more number of days for physiological maturity (118.0 days) and was on par with 150 % RDF (1144.4 days).

Interaction effect of planting windows and fertility levels showed significant difference in GDD, PTU and HTU accumulation. Planting during 1st week of October along with application of 200 % RDF recorded higher GDD, PTU and HTU accumulation (1591.1 ^{0}C day, 17888.3 ^{0}C day hr and 12307.4 ^{0}C day hr respectively. Similarly, it recorded more number days for physiological maturity.

Grain and biomass yield

Planting during 1st week of October recorded significantly higher grain yield and stover yield (8788 and 1220 kg ha^{-1} respectively) and it was on par with planting during 2nd week of October (8644 and 11980 kg ha^{-1} respectively) **(Table 3 and Fig.2).**As planting delayed beyond 2nd week of October, there was reduction in grain and stover yield significantly. The lowest grain and stover yield was recorded from crop sown during 1st week of November. Grain and stover yield differed significantly due to fertility levels. Application of 200 % RDF recorded significantly higher grain and stover yield (8320 and 11950 kg ha^{-1} respectively) and it was on par with application of 150 % RDF (8022 and 11410 kg ha^{-1} respectively).

Interaction effect of planting windows and fertility levels showed significant difference in grain and stover yield. Planting during 1st week of October along with application of 200 % RDF recorded significantly higher grain and stover yield (9142 and 13050 kg ha^{-1} respectively) and it was found on par with planting during 2nd week of October along with application of 200 % and 150 % RDF, planting during 1st week of October along with application of 150 % RDF and 100 % RDF. There is no significant difference in harvest index due to planting windows and fertility levels.

Nutrient use efficiency in winter maize (NUE) Agronomic efficiency of nitrogen (AE_N), phosphorus (AE_P) and potassium (AE_K)

AE_N, AE_P and AE_K were significantly higher with planting during 1st week of October (22.80, 52.63 and 52.63 kg kg^{-1} respectively) and were on par with planting during 2nd week of October (21.80, 48.72 and 48.72 kg kg^{-1} respectively) **(Table 4)**. Significantly higher AE_N, AE_P and AE_K were recorded with application of 100 % RDF (23.41, 53.93 and 53.93 kg kg^{-1} respectively).Interaction of planting windows and fertility levels recorded significant difference in AE_N, AE_P and AE_K. Planting during 1st week of October along with application of 100 % RDF recorded significantly higher AE_N, AE_P and AE_K (29.59, 68.29 and 68.29 kg kg^{-1} respectively) and it was found on par with planting during 2nd week of October along with application of 100 % and planting during 3rd week of October along with application of 100 % RDF.

Physiological efficiency of nitrogen (PE_N), phosphorus (PE_P) and potassium (PE_K)

PE_N, PE_P and PE_K were higher with planting during 1st week of November (53.80, 209.01 and 69.58 kg ha^{-1} respectively). Among fertility levels, higher PE_N, PE_P and PE_K were with application of 100 % RDF (50.67, 196.68 and 69.65 kg ha^{-1} respectively). Interaction effect among planting windows and fertility levels showed significant difference with PE_N and significantly higher PE_N was recorded during 1st week of November planting along with application of 100 % RDF (59.50 kg ha^{-1}). Interaction effect found non-significant with respect to PE_P and PE_K.

Recovery efficiency of nitrogen (RE_N), phosphorus (RE_P) and potassium (RE_K)

PE_N, PE_P and PE_K were significantly higher with planting during 1st week of October (47.92, 29.32 and 78.99 % respectively) and were on par with planting during 2nd week of October (44.36, 27.70 and 73.04 % respectively). Among fertility levels, significantly higher PE_N, PE_P and PE_K were recorded with application of 100 % RDF (49.12, 31.52 and 81.23 % respectively).

Treatment combinations of planting windows and fertility levels recorded significant difference in RE_N, RE_P and RE_K. Planting during 1st week of October along with application of 100 % RDF recorded significantly higher RE_N, RE_P and RE_K (62.19, 38.43 and 102.52 % respectively) and it was found on par with planting during 2nd week of October along with application of 100 % and planting during 3rd week of October along with application of 100 % RDF.

Energetics

Energetics of winter maize significantly influenced by planting windows and fertility levels. The output energy, net energy, energy use efficiency and energy productivity were significantly higher from 1st week of October planting (281233.7 MJ ha^{-1}, 258121.4 MJ ha^{-1}, 12.40 and 0.39 kg MJ^{-1} respectively) **(Table 5).** However, it was found on par with planting during 2nd week of October (276831.5 MJ ha^{-1}, 253719.2 MJ ha^{-1}, 12.19 and 0.38 kg MJ^{-1} respectively). Whereas, the

specific energy was significantly higher in 1st week of November planting (3.43 MJ kg^{-1}).

Among fertility levels, significantly higher output energy, net energy and specific energy were recorded with application of 200 % RDF (271692.2 MJ ha^{-1}, 244035.4 MJ ha^{-1} and 3.36 MJ kg^{-1} respectively). Whereas, The energy use efficiency and energy productivity were significantly higher with application of 100 % RDF (13.06 and 0.40 kg MJ^{-1} respectively).Combination effect showed that the output energy and net energy were significantly higher in 1st week of October planting along with 200 % RDF (297515.0 MJ ha^{-1} and 269857.8 MJ ha^{-1} respectively). However, it was on par with planting during 2nd week of October along with 200 % RDF and planting during 1st week of October along with 150 % RDF. The energy use efficiency and energy productivity were significantly higher with planting during 1st week of October along with application of 100 % RDF (14.24 and 0.45 kg MJ^{-1} respectively). However, it was on par with planting during 2nd week of October along with 100 % RDF and planting during 3rd week of October along with 100 % RDF. The specific energy was significantly higher in 1st week of November planting along with 200 % RDF (3.85 MJ kg^{-1}).

Bio-economics

Significantly higher gross return, net return and B-C ratio was recorded with planting during 1st week of October (USD 2,331 ha^{-1}, USD 1,409 ha^{-1} and 2.53 respectively) and it was on par with planting during 2nd week of October (USD 2,293 ha^{-1}, USD 1,371 ha^{-1} and 2.49 respectively). Among fertility levels, significantly higher gross return, and net return were recorded with application of 200 % RDF (USD 2,211ha^{-1} and USD 1,231 ha^{-1} respectively). There was no significant effect observed with respect to B-C ratio among fertility levels **(Table 6).**Interaction effect showed that significantly higher gross return and net return were recorded with planting during 1st week of October along with application 200 % RDF (USD 2,429 ha^{-1} and USD 1,462 ha^{-1} respectively) and it was on par with planting during 2nd week of October along with application 200 % RDF (USD 2,392 ha^{-1} and USD1,425 ha^{-1} respectively) and planting during 1st week of October along with application 150 % RDF (USD 2,338 ha^{-1} and USD 1,416 ha^{-1} respectively). Significantly higher B-C ratio was

recorded with planting during 1st week of October along with application 150 % RDF.

Discussion

Productivity of winter maize as influenced by planting windows

The optimum date of planting is important for winter maize so that the genotype grown can complete its life cycle and express its full potential under optimum environmental conditions. For optimization of yield, planting at the appropriate time is very important as delayed planting can lead to a linear decrease in grain and stover yields[37]. Early planting in October significantly recorded higher productivity. Planting during October 1st week recorded 1.65, 8.04, 18.17 and 30.53 per cent linear increase in grain yield compared to planting during 2nd, 3rd, 4th week of October and 1st week of November respectively (Table 3 and Fig. 2). Higher grain yield obtained from October 1st week planting was attributed to significant improvement in yield characters and dry matter accumulation (Fig.1a). Similar results were also obtained[38]. Late planting would lead to a lesser row number and less grain numbers in the rows of maize[38]. Further, increase in grain yield and yield attributes in first week of October planting was due to improved growth parameters *viz.,* number of green leaves per plant, leaf area, leaf area index, total dry matter production (Fig. 1a), absolute growth rate (AGR) and crop growth rate (CGR) as a result of higher accumulation of growing degree days (GDD), photothermal units (PTU) and heliothermal units (HTU) compared to delayed planting (Table 2). Similar results were obtained by Swetha[39] who reported that early planting of maize recorded higher grain yield compared to other delayed planting due to higher accumulation of GDD, PTU and HTU. Sutton and Stucker[40] reported that delayed planting caused shortening of growing degree days (GDDs) accumulation during planting to physiological maturity.

There was optimum climatic condition (maximum mean temperature 27.9 ^{o}C and minimum mean temperature 19 ^{o}C in October month) prevailed for crop sown during first and second week of October (early) planting of winter maize; while, delayed planting recorded reduced growth in terms of leaf area and dry matter accumulation. Optimum temperature for maize germination is 21

^{o}C, for growth 32 ^{o}C and for tasselling 25-30 ^{o}C[41]. Late sown crop experienced average lower temperature than optimum (18 ^{o}C for germination, 23 ^{o}C for growth and 23 ^{o}C for tasseling). Further lesser availability of solar radiation (PTU) as a result of shorter day lengths in late planting condition leads shorter growing period (Table 2) which reduced the vegetative growth, dry matter accumulation (Fig. 1a) and finally the yield[42,43]. Environmental changes associated with different planting windows (sunshine and temperature) have a modifying effect on growth and development of maize plants[41]. In early planted maize, better photosynthesis was observed as evidenced by more leaf area index and accumulation of photosynthetes due to favourable climatic conditions[45]. Late planting brings horse weather parameters such as temperature, solar radiation, humidity during crop season which adversely affect the morphology, plant physiology and molecular level of plants[46].

Productivity of winter maize as influenced by fertility levels

Application 200 % RDF increased the grain yield by 3.71 and 10.98 per cent compared to 150 % and 100 % RDF respectively (Table 3 and Fig.1b). The increased grain yield was due to improved yield attributes. Among several inputs essential for crop production, fertilizer management is of superlative importance. Further improved yield attributes was due to increased leaf area, leaf area index and total dry matter production (Fig. 1b). Steady increase AGR and CGR also play important role towards yield. Increased growth and yield parameters in 200 % RDF were also due to higher available nutrients and their uptake[47]. These results are conformity with the findings of Sreelatha *et al.*[48]. They reported higher yield and it's parameters in higher fertilizer levels (300:105:105 kg N-P_2O_5-K_2O ha^{-1}) in southern India as plant could express its full genetic potential in higher fertility levels and better fertilizer levels reduced the cob barrenness percentage. The results are also in conformity with the findings of Damor *et al.*[49] who reported higher yield and yield attributes of winter maize due to application of higher dose of inorganic fertilizer. There was a movement of photosynthates from source to sink and better physiological process. The results are also in close agreement with the findings of Mathukia *et al.*[50] who reported higher growth and yield attributes at higher nitrogen and phosphorus levels which was due to congenial nutritional environment for plant

system on account of their greater availability from soil, which resulted in greater synthesis of amino acids, proteins and growth promoting substance, which enhanced the meristematic activity and increased the cell division and cell elongation. Further application of higher dose of fertilizer have increased interception, absorption and utilization of radiant energy which in turn increased photosynthesis and thereby plant height, stem girth and finally dry matter accumulation.

Productivity of winter maize as influenced by planting windows and fertility levels

Planting during 1st week of October along with application of 200 % RDF (W_1F_3) recorded significantly higher grain and stover yield (91.42 q ha^{-1} and 130.5 q ha^{-1} respectively) and it was on par with planting during 2nd week of October along with application of 200 % RDF (W_2F_3) (Table 3 and Fig.1c). and planting during 1st week of October along with application of 150 % RDF (W_1F_2). The increased grain yield and stover yield was due to improved yield attributes. Increase in yield and yield attributes was due higher growth in terms of number of green leaves per plant, leaf area, leaf area index and total dry matter production (Fig. 1c) which increased AGR and CGR. These results are similar with findings of Verma *et al.*[51] and they reported early planting and higher fertilizer levels favours good plant height, leaf area index and dry weight per plant due to favourable climatic conditions especially temperature which increased metabolic activities, increased assimilation and cell division within the plant. Increased growth attributes at W_1F_3 was due to higher accumulation of GDD, PTU and HTU (Table 2). The increased application of nutrients increases the uptake of nutrients by plants in winter maize which might be due congenial nutrient environment in soil and availability higher nutrients in rhizospere[49,52].

Nutrients use efficiency (NUE) as influenced by planting windows

Nutrients use efficiency (NUE) shows the ability of crops to take up and utilize nutrients for maximum yields. NUE depends on the plant's ability to take up nutrients efficiently from the soil, but also depends on internal transport, storage and remobilization of nutrients. NUE of applied fertilizers is very low

due to many reasons like surface runoff, leaching, volatilization, denitrification and fixation in the soil. The increased yield levels show the higher nutrient use efficiency. The better planting date will provide the congenial environment to plants to uptake more nutrients so that productivity of crops is increased.

Significantly higher AE_N, AE_P and AE_K were recorded from crop sown during 1^{st} week of October and lower from crop sown during 1^{st} week of November (Table 4) due to higher grain yield in the first planting compared to yield from delayed planting. Similarly, higher RE_N, RE_P and RE_K were recorded from crop sown during 1^{st} week of October (Table 4) due to higher nutrient uptake. And lower recovery efficiency was obtained from crop sown during 1^{st} week of November on the contrary the highest PE was recorded when crop was sown during 1^{st} week of November for nitrogen, phosphorus and potassium and was on par with crop sown during 1^{st} week of October (Table 4). This indicates more capacity of plant to increase yield with per unit nutrient uptake. Similar results were reported by Srivastava *et al.*[53] in maize crop and Sunita devi *et al.*[54] in transplanted rice crop.

Nutrient use efficiency (NUE) as influenced by fertility levels

Significantly higher AE_N, AE_P and AE_K were recorded with application of 100 % RDF (Table 4). On the contrary lower agronomic efficiency for nutrients was recorded with higher fertility levels. For nitrogen, similar results were noticed by Vanlauwe *et al.*[55] in maize based system and according to them higher agronomic efficiency was recorded in lower nitrogen level. The similar results were also obtained by Caviglia *et al.*[56] who concluded higher agronomic efficiency in lower fertilizer level in both early and late sown maize. Similarly higher PE_N, PE_P and PE_K were recorded with application of 100 % RDF and lower physiological efficiency was recorded with higher fertility levels (Table 4). Similarly, the higher RE_N, RE_P and RE_K were obtained with application of 100 % RDF, whereas lower recovery efficiency was observed in higher fertility levels (Table 4). Lesser the application of fertilizer higher will be the nutrient use efficiency[57,58]. This result is also conformity with the findings of Choudhary *et al.*[59] and they concluded that yield increase was decreased with each increased level of nitrogen application. The highest agronomic nitrogen use

efficiency was recorded with 60 kg N/ha. N level of 180 kg/ha recorded the least. Yield increase due to per unit increase in uptake of N was decreased with increased levels of N application. The highest NUE always occurs at the lower parts of the yield response curve, where fertilizer inputs are the lowest. The effectiveness of fertilizers in increasing crop yields and optimizing farmer profitability should not be sacrificed for the sake of efficiency alone. There must be balance between optimum NUE and optimal crop productivity [60].

Increased levels of fertilizer tend to lower the productive efficiency. Apparent recovery, which indicates the efficiency of absorption of applied nutrients, decreased at higher levels of fertilizer application. Each crop is having definite capacity to absorb a certain amount of nutrients, beyond which nutrients could not be taken up by the plants. When limited quantity of nutrients was applied, the crop can efficiently absorb the available nutrients in the soil solution and there by reduced the nutrient losses and increases the NUE[61-64].

Interaction effect of nutrient use efficiency (NUE) as influenced by fertility levels

Interaction effect showed the higher agronomic efficiency with planting during 1st week of October along with application of 100 % RDF. The higher recovery efficiency for nitrogen, phosphorus and potassium was recorded with planting during 1st week of October along with application of 100 % RDF whereas, higher physiological efficiency was recorded with planting during 1st week of November along with application of 100 % RDF (Table 4). The higher agronomic efficiency in October 1st week planting along with 100 % RDF was due to higher grain yield in early planting and lower fertility level which increased the efficiency. The recovery efficiency was also higher in October 1st week planting which was due to higher applied nutrient uptake. The higher physiological efficiency was recorded during 1st week of November which might be due to more capacity of plant to increase yield with per unit nutrient uptake. Lesser the application of fertilizer, higher will be the nutrient use efficiency[53,58,65-68].

Energetics as influenced by planting windows

In agriculture development, the energy audit of various resources plays a key role in resource management. Under the changing global climatic conditions and increasingly growing energy demands necessitate the development of a production system which utilizes less energy and produces more energy as output. The energetics was calculated per hectare and then these input data were multiplied with conversion factor of its energy equivalent. The energy indices were determined by using standard equation[30].

The total input energy was lower for early planting windows due to lower irrigation requirement[71]. The productivity of the crop sown on 1st and 2nd week of October were higher than delayed sown crop which resulted in higher output energy and lower output energy was recorded with crop sown during 1st week of November. The net energy was also higher from early sown winter maize because of higher output energy during these planting windows and lower net energy was recorded with crop sown during 1st week of November. Further, energy use efficiency was highest with crop sown during 1st week of October and was found on par with planting during 2nd week of October and lowest energy use efficiency was recorded in last planting during 1st week of November (Fig 3a). The higher energy use efficiency in early sown crop compared to late planting was due to higher grain yield and output of energy. Energy productivity was also higher from crop sown during 1st week of October and was on par with planting during 2nd week of October. Lower energy productivity was observed in 1st week of November planting (Fig. 3a). Higher energy productivity was directly correlated with higher productivity. The specific energy was higher in 1st week of November planting and lower specific energy was recorded in 1st week of October planting (Fig. 3a). The higher specific energy in delayed planting was due to higher energy requirement to produce unit yield. The same results were observed by Puniya *et al.*[72]. The energy use efficiency (EUE) was significantly positively correlated with net energy return, energy productivity, energy intensity, energy output, helio-thermal use efficiency, heat use efficiency and significant negatively correlated with specific energy and helio-thermal units[71,72].

Energetics as influenced by fertility levels

According to many researchers the inputs such as fuel, electricity, machinery, seed, fertilizer and chemical take significant share of the energy supplies to the production system in modern agriculture. Foremost important among them is careful management of fertilizers, because on the one hand, in many cases it alone share more than 50 per cent of total input energy used in a system and the other, it is the most imperative growth factor for proper growth and development of plants[11]. It was observed that, the fertilizers had the highest rate of energy equivalency of all the inputs used in maize production at 51.5 per cent[12].

The total energy input in 200 % RDF was higher than other fertility levels due higher rate of application. Aakash *et al.*[9] reported that fertilizer management is very essential since it utilized almost 70% of total input energy used in maize production. Application of 200 % RDF recorded higher total output energy. Lower total output of energy was recorded with application of 100 % RDF due lower grain yield. Significantly higher grain and stover yield in higher fertility levels increased the total output energy. Hence, the net energy was higher in 200 % RDF and lower net energy was recorded with application of 100 % RDF. While, the energy use efficiency and energy productivity were higher in 100 % RDF (Fig. 3b). The higher energy use efficiency was due to higher ratio of output to input energy. Similarly, higher energy productivity was due to higher ratio of yield to input energy. The specific energy was higher with application 200 % RDF (Fig. 3b). This was due to higher energy requirement to produce unit yield in 200 % RDF[73-76]. The findings of Khokhar *et al.*[63] are similar to above results and they concluded higher input energy, output energy and energy balance in higher fertility levels and higher energy use efficiency and energy productivity in lower fertility levels in both maize and wheat crop. Singh *et al.*[60] reported similar results and they reported higher output energy and net energy return in site specific nutrient management compared to farmer practice and RDF due to higher yield levels in precision nutrient management practices. Choudhary *et al.*[59], Biswasi *et al.*[77], Jayadeva and Prabhakar shetty[78] also found that higher input energy, output energy and net energy in higher fertility levels compared to lower fertility levels.

Interaction effect of planting windows and fertility levels on energetics

Interaction of planting windows and fertility levels plays an important role in energy flow in winter maize. Relatively higher input energy was recorded in 1st week of November planting along with 200 % RDF. Planting during 1st week of October along with application 200 % RDF (W_1F_3)(Fig.3c) recorded higher total output energy compared to other treatment combinations. The higher output energy was due to higher yield levels in W_1F_3. Higher net energy was recorded with planting during 1st week of October along with application of 200 % RDF and it was found on par with early planting during 2nd week of October and 1st week of October along with application of either 200 % RDF or 150 % RDF. This was because there was higher input energy use which increased the grain and stover yield resulting in increased the total output energy and net energy, whereas higher energy use efficiency was recorded with planting during 1st week of October along with application of 100 % RDF and was found on par with planting during 2nd week of October along with application of 100 % RDF, planting during 3rd week of October along with application of 100 % RDF (Fig. 3c). This was because the higher ratio of output to input energy. Similarly higher energy productivity was recorded with planting during 1st week of October along with application of 100 % RDF and it was on par with planting during 2nd week of October along with application of 100 % RDF, planting during 3rd week of October along with application of 100 % RDF (Fig. 3c). Higher energy productivity was due to higher ratio of grain yield to energy input. Higher specific energy was recorded with planting during 1st week of November along with application of 200 % RDF and was found on par with planting during 4th week of October along with application of 200 % RDF (Fig. 3c). This was because in this treatment combination there was a higher requirement of energy to produce unit yield[72,73,79].

Bio-economics

Significantly higher gross return, net return and B-C ratio was recorded with planting during 1st week of October and it was on par with planting during 2nd week of October. The higher gross return and net return were due to higher grain yield and stover yield in these two planting windows, whereas

significantly lower gross return, net return and B-C ratio recorded with planting at 1st week of November was due to lower productivity[46]. Among the fertility levels, significantly higher gross return and net return was recorded with application of 200 % RDF and was on par with application of 150 % RDF due to higher grain and stover yield in these two fertility levels, whereas significantly lower gross return and net return was recorded with application of 100 % RDF due to its lower grain and stover yield. There is no significant difference with respect to B-C ratio[69].

Interaction effect showed that significantly higher gross return and net return were recorded with planting during 1st week of October along with application of 200 % RDF and was on par with planting during 2nd week of October with 200 % RDF and planting during 1st week of October with 150 % The higher gross return and net return in these interactions were due to higher grain and stover yield, whereas significantly lower gross return and net return were recorded with planting during 1st week of November along with application of 100 % RDF was due to its lower productivity of crop[70].

Conclusion

Planting of maize in winter season is more suitable than rainy season by looking at crop growth and productivity. The best planting windows to obtain higher productivity, NUE, energy use efficiency, energy productivity, net return and B-C ratio were 1st and 2nd week October. Among fertility levels, application of 200 % and 150 % RDF showed higher productivity. Whereas, higher NUE, energy use efficiency and energy productivity was recorded with 100 % RDF. Considering all these variables, it could be inferred that planting maize during 1st or 2nd week October along with application 150 % RDF is most productive, remunerative and energy efficient in south India.

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Table 1. Energy equivalents (MJ unit^{-1}) used for energy input and output calculations.

Particulars	Unit	Energy equivalent (MJ ha^{-1})	References
I. Inputs			
1. Human labour			
Adult man	hr	1.96	Barut *et al.*[24], Kumar *et al.*[25], Shahin *et al.*[26], Yadav *et al.*[27]
Adult women	hr	1.57	Devi *et al.*[28]
2. Bullocks	Pair-hr	10.1	Binning *et al.*[21], Gopalan *et al.*[20], Mittal *et al.*[19], Singh[22] and Subbian *et al.*[23]
3. Fuel and machinery			
Diesel	1 L	56.31	Barut *et al.*[24], Kumar *et al.*[25], Shahin *et al.*[26], Singh *et al.*[29], Yadav *et al.*[27]
Tractor	hr	62.7	Singh *et al.*[29]
4. Manures and fertilizers			
Farm Yard Manure	1 t	303.1	Avval Mousavi *et al.*[30]
Nitrogen	kg	60.6	Singh *et al.*[29]
Phosphorus	kg	11.1	Singh *et al.*[29]
Potassium	kg	6.7	Singh *et al.*[29]

Zinc sulphate	kg	20.9	Nassiri and Singh[31]
5. Maize seeds	kg	15.2	Rahman and Rahman[32], Yadav *et al.*[27]
6. Insecticide	kg	120	Kumar *et al.*[25], Shahin *et al.*[26], Shahan *et al.*[33]
7. Irrigation water	M^3	1.02	Devasenapathy *et al.*[34]
II. Outputs			
Maize grains	kg	14.7	Barut *et al.*[24], Kumar *et al.*[25], Rahman and Rahman[32], Shahin *et al.*[26], Yadav *et al.*[27], Zahedi *et al.*[35]
Maize stover	kg	12.5	Barut *et al.*[24], Kumar *et al.*[25], Rahman and Rahman[32], Shahin *et al.*[26], Yadav *et al.*[27] and Zahedi *et al.*[35]

Table 2: Days to physiological maturity, growing degree days, photo thermal units and heliothermal units of winter maize as influenced by sowing windows and fertility levels

Treatment	Days to physiological maturity	Growing degree days (^{0} C day)	Photo thermal units (^{0} C day hr)	Heliothermal units (^{0} C day hr)
Factor I: Sowing windows				
W_1: 1st week of October	120.0[a]	1530.1[a]	17371.3[a]	11758.5[a]
W_2: 2nd week of October	116.1[ab]	1493.4[a]	16578.0[b]	11655.0[b]
W_3: 3rd week of October	114.2[ab]	1466.9[b]	16268.3[c]	11597.4[c]
W_4: 4th week of October	112.0[bc]	1444.9[c]	15966.6[d]	11381.6[d]
W_5: 1st week of November	108.9[c]	1242.4[d]	15416.5[e]	11274.0[e]
S.Em ±	**1.26**	**2.53**	**19.33**	**12.83**
Factor II: Fertility levels				
F_1: 100 % RDF	110.5[b]	1392.7[c]	15602.8[c]	11149.0[c]
F_2: 150% RDF	114.4[a]	1421.0[b]	16330.9[b]	11373.3[b]
F_3: 200% RDF	118.0[a]	1493.5[a]	17026.7[a]	12077.5[a]
S.Em ±	**1.63**	**3.27**	**24.95**	**16.56**
Interaction (W×F)				
W_1F_1: 1st week of Oct + 100 % RDF	116.7[a-d]	1471.4[e]	16838.2[d]	11409.2[f]
W_1F_2: 1st week of Oct + 150 % RDF	120.5[ab]	1527.8[c]	17387.3[b]	11558.9[e]
W_1F_3: 1st week of Oct + 200 % RDF	122.9[a]	1591.1[a]	17888.3[a]	12307.4[a]
W_2F_1: 2nd week of Oct + 100 % RDF	111.8[b-e]	1444.4[f]	15849.2[g]	11156.4[g]
W_2F_2: 2nd week of Oct + 150% RDF	116.3[a-d]	1474.4[e]	16550.3[e]	11652.6[d]
W_2F_3: 2nd week of Oct + 200 % RDF	120.2[ab]	1561.3[b]	17334.6[b]	12155.9[b]
W_3F_1: 3rd week of Oct + 100 % RDF	110.4[c-e]	1433.4[f]	15594.6[h]	11351.9[f]
W_3F_2: 3rd week of Oct + 150 % RDF	114.2[a-e]	1445.0[f]	16193.0[f]	11365.4[f]
W_3F_3: 3rd week of Oct + 200 % RDF	118.2[a-c]	1522.4[c]	17017.2[c]	12074.7[b]
W_4F_1: 4th week of Oct + 100 % RDF	108.2[de]	1397.8[g]	15175.1[i]	11012.7[h]
W_4F_2: 4th week of Oct + 150 % RDF	112.0[b-e]	1440.0[f]	15928.3[g]	11170.6[g]
W_4F_3: 4th week of Oct + 200 % RDF	116.5[a-d]	1497.0[d]	16796.5[d]	11961.3[c]
W_5F_1: 1st week of Nov + 100 % RDF	105.3[e]	1213.9[i]	14556.9[j]	10814.6[i]
W_5F_2: 1st week of Nov + 150 % RDF	109.2[c-e]	1218.0[i]	15595.6[h]	11119.0[g]
W_5F_3: 1st week of Nov + 200 % RDF	112.3[b-e]	1295.5[h]	16097.0[f]	11888.3[c]
S.Em ±	**2.82**	**6.67**	**43.21**	**28.6**

Table 3: Grain yield, stover yield and harvest index of winter maize as influenced by sowing windows and fertility levels

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
Factor I: Sowing windows			
W_1: 1st week of October	8787^{a}	12200^{a}	41.99^{a}
W_2: 2nd week of October	8644^{ab}	11980^{ab}	41.86^{a}
W_3: 3rd week of October	8133^{b}	11320^{bc}	41.83^{a}
W_4: 4th week of October	7436^{c}	10750^{cd}	41.03^{a}
W_5: 1st week of November	6732^{d}	10330^{d}	39.54^{a}
S.Em ±	**154.4**	**209.5**	**0.62**
Factor II: Fertility levels			
F_1: 100 % RDF	7497^{b}	10590^{b}	41.34^{a}
F_2: 150% RDF	8022^{a}	11410^{a}	41.34^{a}
F_3: 200% RDF	8320^{a}	11950^{a}	41.06^{a}
S.Em ±	**199.3**	**269.2**	**0.80**
Interaction (W×F)			
W_1F_1: 1st week of Oct + 100 % RDF	8403^{a-c}	11280^{b-g}	42.86^{a}
W_1F_2: 1st week of Oct + 150 % RDF	8814^{ab}	12270^{a-c}	41.83^{a}
W_1F_3: 1st week of Oct + 200 % RDF	9142^{a}	13050^{a}	41.26^{a}
W_2F_1: 2nd week of Oct + 100 % RDF	8141^{a-d}	11000^{c-g}	42.23^{a}
W_2F_2: 2nd week of Oct + 150% RDF	8783^{ab}	12170^{a-d}	41.93^{a}
W_2F_3: 2nd week of Oct + 200 % RDF	9007^{ab}	12780^{ab}	41.40^{a}
W_3F_1: 3rd week of Oct + 100 % RDF	78.9^{b-e}	10690^{d-g}	42.33^{a}
W_3F_2: 3rd week of Oct + 150 % RDF	8217^{a-d}	11480^{b-f}	41.76^{a}
W_3F_3: 3rd week of Oct + 200 % RDF	8321^{a-c}	11800^{a-e}	41.40^{a}
W_4F_1: 4th week of Oct + 100 % RDF	6913^{ef}	1019^{f0g}	40.53^{a}
W_4F_2: 4th week of Oct + 150 % RDF	7444^{c-e}	10780^{c-g}	41.23^{a}
W_4F_3: 4th week of Oct + 200 % RDF	7948^{b-e}	11290^{b-g}	41.33^{a}
W_5F_1: 1st week of Nov + 100 % RDF	6164^{f}	9780^{g}	38.76^{a}
W_5F_2: 1st week of Nov + 150 % RDF	6850^{ef}	10380^{e-g}	39.96^{a}
W_5F_3: 1st week of Nov + 200 % RDF	7180^{d-f}	10840^{c-g}	39.9^{a}
S.Em ±	**345.0**	**466.1**	**1.37**

Highest values were denoted with 'a' followed by the next alphabets for lower values (b, c, d *etc*.). Value denoted by same small letter in the column does not differ significantly at 0.05 level of significance.

Table 4: Nutrient use efficiency of nitrogen, phosphorus and potassium as influenced by sowing windows and fertility levels

Treatment	AE_N (kg kg^{-1})	AE_P (kg kg^{-1})	AE_K (kg kg^{-1})	PE_N (kg ha^{-1})	PE_P (kg ha^{-1})	PE_K (kg ha^{-1})	RE_N (%)	RE_P (%)	RE_K (%)
Factor I: Sowing windows									
W_1: 1st week of October	22.80^{a}	52.63^{a}	52.63^{a}	49.01^{ab}	184.24^{a}	68.57^{a}	47.92^{a}	29.32^{a}	78.99^{a}
W_2: 2nd week of October	21.80^{a}	48.72^{ab}	48.72^{ab}	47.94^{b}	181.72^{a}	68.65^{a}	44.36^{a}	27.70^{a}	73.04^{ab}
W_3: 3rd week of October	19.80^{a}	45.69^{b}	45.69^{b}	48.37^{b}	184.45^{a}	66.42^{a}	41.59^{a}	26.19^{a}	69.09^{b}
W_4: 4th week of October	16.14^{b}	37.25^{c}	37.25^{c}	48.74^{ab}	194.31^{a}	69.50^{a}	33.92^{b}	21.97^{b}	56.01^{c}
W_5: 1st week of November	12.74^{c}	29.40^{d}	29.40^{d}	53.80^{a}	209.01^{a}	69.58^{a}	26.78^{c}	18.04^{c}	44.04^{d}
S.Em ±	**0.75**	**1.74**	**1.74**	**1.31**	**17.76**	**4.28**	**1.70**	**0.81**	**1.98**
Factor II: Fertility levels									
F_1: 100 % RDF	23.41^{a}	53.93^{a}	53.93^{a}	50.67^{a}	196.68^{a}	69.65^{a}	49.12^{a}	31.52^{a}	81.23^{a}
F_2: 150% RDF	18.03^{b}	41.06^{b}	41.06^{b}	49.73^{a}	187.26^{a}	68.28^{a}	37.39^{b}	23.48^{b}	61.65^{b}
F_3: 200% RDF	14.51^{c}	33.19^{c}	33.19^{c}	48.32^{a}	188.29^{a}	67.69^{a}	30.23^{c}	18.91^{c}	49.82^{c}
S.Em ±	**0.97**	**2.25**	**2.25**	**1.69**	**22.93**	**5.53**	**2.20**	**1.04**	**2.56**
Interaction (W×F)									
W_1F_1: 1st week of Oct + 100 % RDF	29.59^{a}	68.29^{a}	68.29^{a}	47.54^{b}	185.96^{a}	66.47^{a}	62.19^{a}	38.43^{a}	102.52^{a}
W_1F_2: 1st week of Oct + 150 % RDF	21.55^{bc}	49.74^{bc}	49.74^{bc}	49.54^{b}	185.99^{a}	72.13^{a}	45.29^{bc}	27.28^{b}	74.66^{b}
W_1F_3: 1st week of Oct + 200 % RDF	17.26^{c-f}	39.83^{c-f}	39.83^{c-f}	49.95^{b}	180.76^{a}	67.10^{a}	36.27^{c-f}	22.22^{b-e}	59.79^{c-e}
W_2F_1: 2nd week of Oct + 100 % RDF	27.17^{a}	62.20^{a}	62.20^{a}	47.55^{b}	174.68^{a}	70.35^{a}	56.64^{ab}	35.73^{a}	93.13^{a}
W_2F_2: 2nd week of Oct + 150% RDF	21.41^{bc}	46.68^{cd}	46.68^{cd}	48.66^{b}	184.99^{a}	66.97^{a}	42.51^{cd}	26.43^{bc}	70.08^{bc}
W_2F_3: 2nd week of Oct + 200 % RDF	16.81^{c-f}	37.25^{c-g}	37.25^{c-g}	47.61^{b}	185.48^{a}	68.63^{a}	33.92^{c-g}	20.93^{c-e}	55.92^{c-f}
W_3F_1: 3rd week of Oct + 100 % RDF	25.96^{ab}	59.92^{ab}	59.92^{ab}	49.71^{b}	190.37^{a}	65.86^{a}	54.57^{ab}	34.58^{a}	91.49^{a}
W_3F_2: 3rd week of Oct + 150 % RDF	18.90^{c-e}	43.62^{c-e}	43.62^{c-e}	47.89^{b}	176.39^{a}	66.52^{a}	39.67^{c-e}	24.89^{b-d}	65.47^{b-d}
W_3F_3: 3rd week of Oct + 200 % RDF	14.52^{d-g}	33.51^{e-g}	33.51^{e-g}	47.51^{b}	186.58^{a}	66.88^{a}	30.52^{d-g}	19.09^{d-f}	50.30^{e-g}
W_4F_1: 4th week of Oct + 100 % RDF	19.67^{cd}	45.41^{c-e}	45.41^{c-e}	49.04^{b}	166.28^{a}	72.02^{a}	41.35^{cd}	27.33^{b}	68.18^{bc}
W_4F_2: 4th week of Oct + 150 % RDF	15.46^{d-g}	35.69^{d-g}	35.69^{d-g}	49.33^{b}	215.34^{a}	69.45^{a}	32.50^{d-g}	20.92^{c-e}	53.57^{d-f}
W_4F_3: 4th week of Oct + 200 % RDF	13.28^{e-g}	30.64^{fg}	30.64^{fg}	47.83^{b}	201.29^{a}	67.01^{a}	27.90^{e-g}	17.63^{ef}	46.27^{e-g}
W_5F_1: 1st week of Nov + 100 % RDF	14.66^{d-g}	33.85^{d-g}	33.85^{d-g}	59.50^{a}	266.11^{a}	73.57^{a}	30.84^{d-g}	21.54^{b-e}	50.84^{e-g}
W_5F_2: 1st week of Nov + 150 % RDF	12.87^{fg}	29.60^{fg}	29.60^{fg}	53.22^{ab}	173.58^{a}	66.32^{a}	26.96^{fg}	17.88^{ef}	44.45^{fg}
W_5F_3: 1st week of Nov + 200 % RDF	10.72^{g}	24.73^{g}	24.73^{g}	48.68^{b}	187.33^{a}	68.84^{a}	22.53^{g}	14.68^{f}	36.82^{g}
S.Em ±	**1.68**	**3.89**	**3.89**	**2.92**	**39.71**	**9.57**	**3.80**	**1.80**	**4.43**

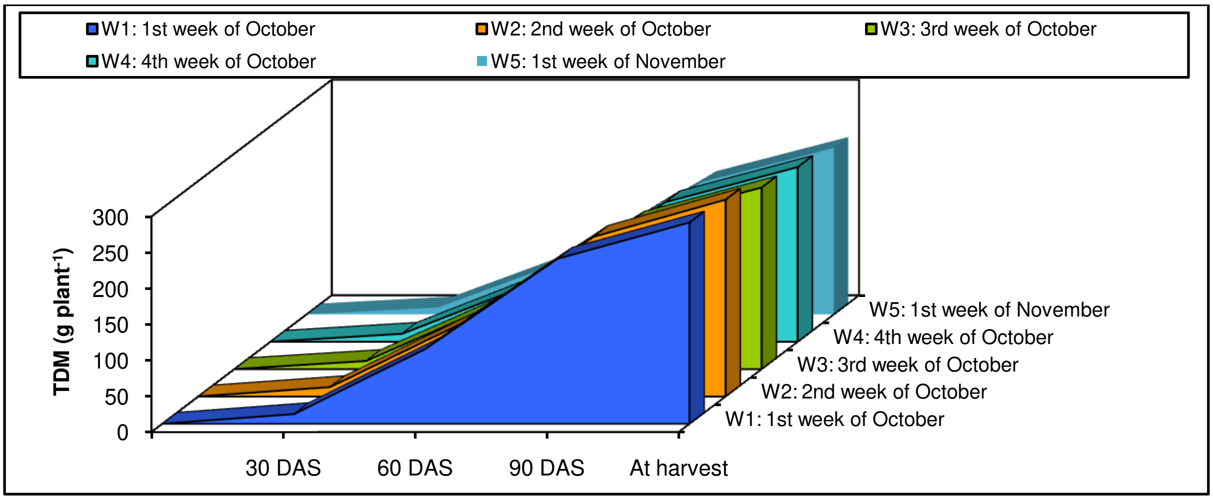
Table 5: Energetics of winter maize as influenced by sowing windows and fertility levels

Treatment	Input energy (MJ ha^{-1})	Output energy (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy use efficiency	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})
Factor I: Sowing windows						
W_1: 1st week of October	23141.7	281233.7^{a}	258121.4^{a}	12.40^{a}	0.39^{a}	2.62^{c}
W_2: 2nd week of October	23141.7	276831.5^{a}	253719.2^{a}	12.19^{ab}	0.38^{ab}	2.65^{c}
W_3: 3rd week of October	23147.6	260631.8^{b}	237519.5^{b}	11.72^{b}	0.36^{b}	2.85^{c}
W_4: 4th week of October	23153.5	243285.6^{c}	220173.3^{c}	10.72^{c}	0.33^{c}	3.12^{b}
W_5: 1st week of November	23153.5	227703.2^{d}	204085.9^{d}	10.03^{d}	0.30^{d}	3.43^{a}
S.Em ±	-	3552.1	3551.66	0.16	0.01	0.06
Factor II: Fertility levels						
F_1: 100 % RDF	18602.6	242543.1^{c}	223672.8^{b}	13.06^{a}	0.40^{a}	2.51^{c}
F_2: 150% RDF	23147.6	259575.7^{b}	236463.4^{a}	11.23^{b}	0.34^{b}	2.92^{b}
F_3: 200% RDF	27692.6	271692.2^{a}	244035.4^{a}	9.94^{c}	0.29^{c}	3.36^{a}
S.Em ±	-	4585.7	4585.1	0.21	0.01	0.08
Interaction (W×F)						
W_1F_1: 1st week of Oct + 100 % RDF	18596.7	264510.1^{c-e}	245942.8^{a-c}	14.24^{a}	0.45^{a}	2.21^{h}
W_1F_2: 1st week of Oct + 150 % RDF	23141.6	281676.0^{a-c}	258563.8^{ab}	12.18^{b}	0.38^{bc}	2.62^{e-h}
W_1F_3: 1st week of Oct + 200 % RDF	27686.7	297515.0^{a}	269857.8^{a}	10.76^{cd}	0.32^{ef}	3.03^{c-e}
W_2F_1: 2nd week of Oct + 100 % RDF	18596.7	257193.0^{c-e}	238625.7^{b-d}	13.85^{a}	0.44^{a}	2.28^{gh}
W_2F_2: 2nd week of Oct + 150% RDF	23141.6	281176.0^{a-c}	258063.7^{ab}	12.17^{b}	0.38^{bc}	2.64^{e-h}
W_2F_3: 2nd week of Oct + 200 % RDF	27686.7	292125.6^{ab}	264468.4^{ab}	10.56^{cd}	0.32^{ef}	3.03^{c-e}
W_3F_1: 3rd week of Oct + 100 % RDF	18602.6	249111.3^{d-f}	230544.0^{c-e}	13.41^{a}	0.42^{ab}	2.38^{f-h}
W_3F_2: 3rd week of Oct + 150 % RDF	23147.6	262982.0^{c-e}	239869.7^{bc}	11.38^{bc}	0.35^{c-e}	2.82^{d-f}
W_3F_3: 3rd week of Oct + 200 % RDF	27692.6	269802.0^{b-d}	242144.8^{bc}	10.36^{c-e}	0.30^{fg}	3.35^{bc}
W_4F_1: 4th week of Oct + 100 % RDF	18608.5	228993.6^{fg}	210426.3^{ef}	12.33^{b}	0.37^{cd}	2.70^{d-g}
W_4F_2: 4th week of Oct + 150 % RDF	23153.5	242888.5^{ef}	219776.2^{c-e}	10.51^{cd}	0.32^{ef}	3.11^{b-d}
W_4F_3: 4th week of Oct + 200 % RDF	27698.5	257974.8^{c-e}	230317.5^{c-e}	9.32^{ef}	0.28^{fg}	3.53^{ab}
W_5F_1: 1st week of Nov + 100 % RDF	18608.5	212907.3^{g}	192825.1^{f}	11.46^{bc}	0.33^{d-f}	3.02^{c-e}
W_5F_2: 1st week of Nov + 150 % RDF	23153.5	229156.2^{fg}	206044.0^{ef}	9.91^{de}	0.29^{fg}	3.40^{bc}
W_5F_3: 1st week of Nov + 200 % RDF	27698.5	241046.0^{ef}	213388.7^{d-f}	8.71^{f}	0.26^{g}	3.85^{a}
S.Em ±	-	7942.7	7941.8	0.37	0.01	0.14

Table 6: Economics of winter maize as influenced by sowing windows and fertility levels

Treatment	Cost of cultivation (USD ha^{-1})	Gross return (USD ha^{-1})	Net return (USD ha^{-1})	B-C ratio
Factor I: Sowing windows				
W_1: 1st week of October	922	2331^{a}	1409^{a}	2.53^{a}
W_2: 2nd week of October	922	2293^{ab}	1371^{a}	2.49^{a}
W_3: 3rd week of October	935	2158^{b}	1223^{b}	2.31^{b}
W_4: 4th week of October	948	1977^{c}	1030^{c}	2.09^{c}
W_5: 1st week of November	948	1795^{d}	848^{d}	1.89^{d}
S.Em ±	-	38.9	38.9	0.04
Factor II: Fertility levels				
F_1: 100 % RDF	889	1991^{b}	1102^{b}	2.24^{a}
F_2: 150% RDF	935	2130^{a}	1196^{ab}	2.28^{a}
F_3: 200% RDF	980	2211^{a}	1231^{a}	2.26^{a}
S.Em ±	-	50.3	50.3	0.05
Interaction (W×F)				
W_1F_1: 1st week of Oct + 100 % RDF	876	2226^{a-d}	1350^{ab}	2.54^{a}
W_1F_2: 1st week of Oct + 150 % RDF	922	2338^{a-c}	1416^{a}	2.55^{a}
W_1F_3: 1st week of Oct + 200 % RDF	968	2429^{a}	1462^{a}	2.51^{a}
W_2F_1: 2nd week of Oct + 100 % RDF	876	2157^{a-e}	1281^{a-c}	2.46^{a}
W_2F_2: 2nd week of Oct + 150% RDF	922	2330^{a-c}	1408^{a}	2.53^{a}
W_2F_3: 2nd week of Oct + 200 % RDF	968	2392^{ab}	1425^{a}	2.47^{a}
W_3F_1: 3rd week of Oct + 100 % RDF	889	2083^{c-g}	1194^{a-d}	2.34^{ab}
W_3F_2: 3rd week of Oct + 150 % RDF	935	2180^{a-e}	1245^{a-c}	2.33^{a-c}
W_3F_3:3rd week of Oct + 200 % RDF	980	2210^{a-d}	1230^{a-c}	2.25^{a-c}
W_4F_1: 4th week of Oct + 100 % RDF	902	1841^{f-h}	940^{d-f}	2.04^{c-e}
W_4F_2: 4th week of Oct + 150 % RDF	948	1978^{d-g}	1031^{c-e}	2.09^{b-e}
W_4F_3: 4th week of Oct + 200 % RDF	993	2111^{b-f}	1118^{b-e}	2.12^{b-d}
W_5F_1: 1st week of Nov + 100 % RDF	902	1648^{h}	746^{f}	1.83^{e}
W_5F_2: 1st week of Nov + 150 % RDF	948	1825^{gh}	878^{ef}	1.93^{de}
W_5F_3: 1st week of Nov + 200 % RDF	993	1914^{e-h}	920^{d-f}	1.93^{de}
S.Em ±	-	87.1	87.1	0.10

Highest values were denoted with 'a' followed by the next alphabets for lower values (b, c, d *etc*.). Value denoted by same small letter in the column does not differ significantly at 0.05 level of significance. (1 USD = 70 INR)



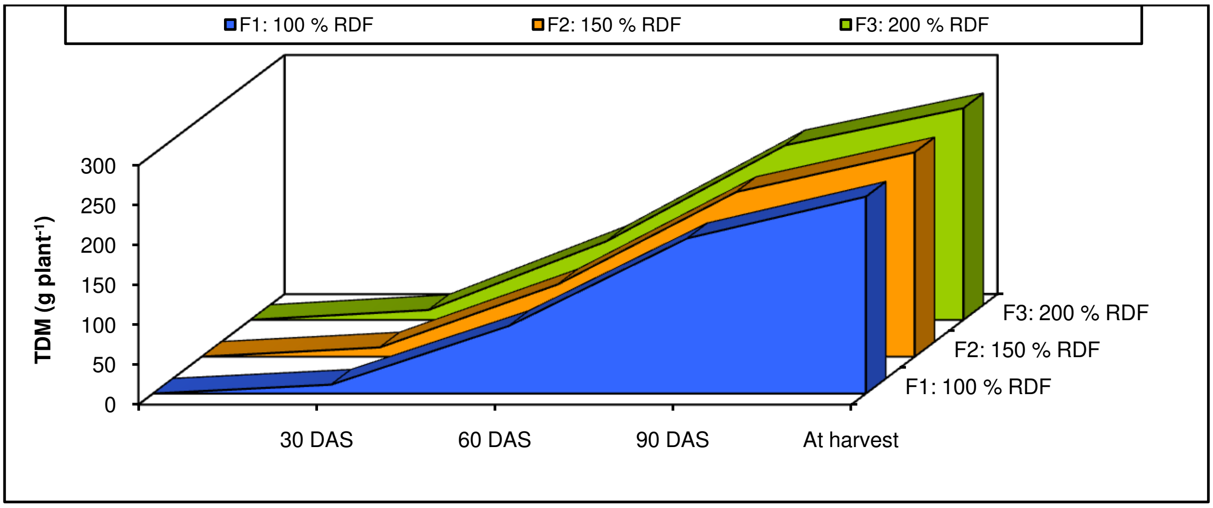


Figure 1b: Total dry matter (TDM) production per plant at different growth stages of winter maize as influenced by fertility

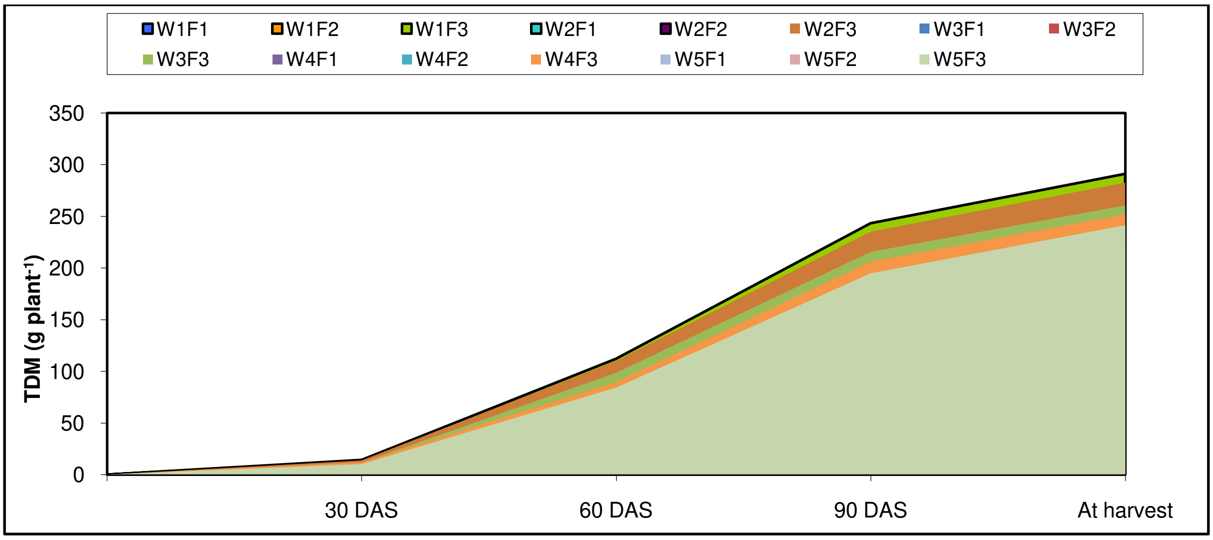
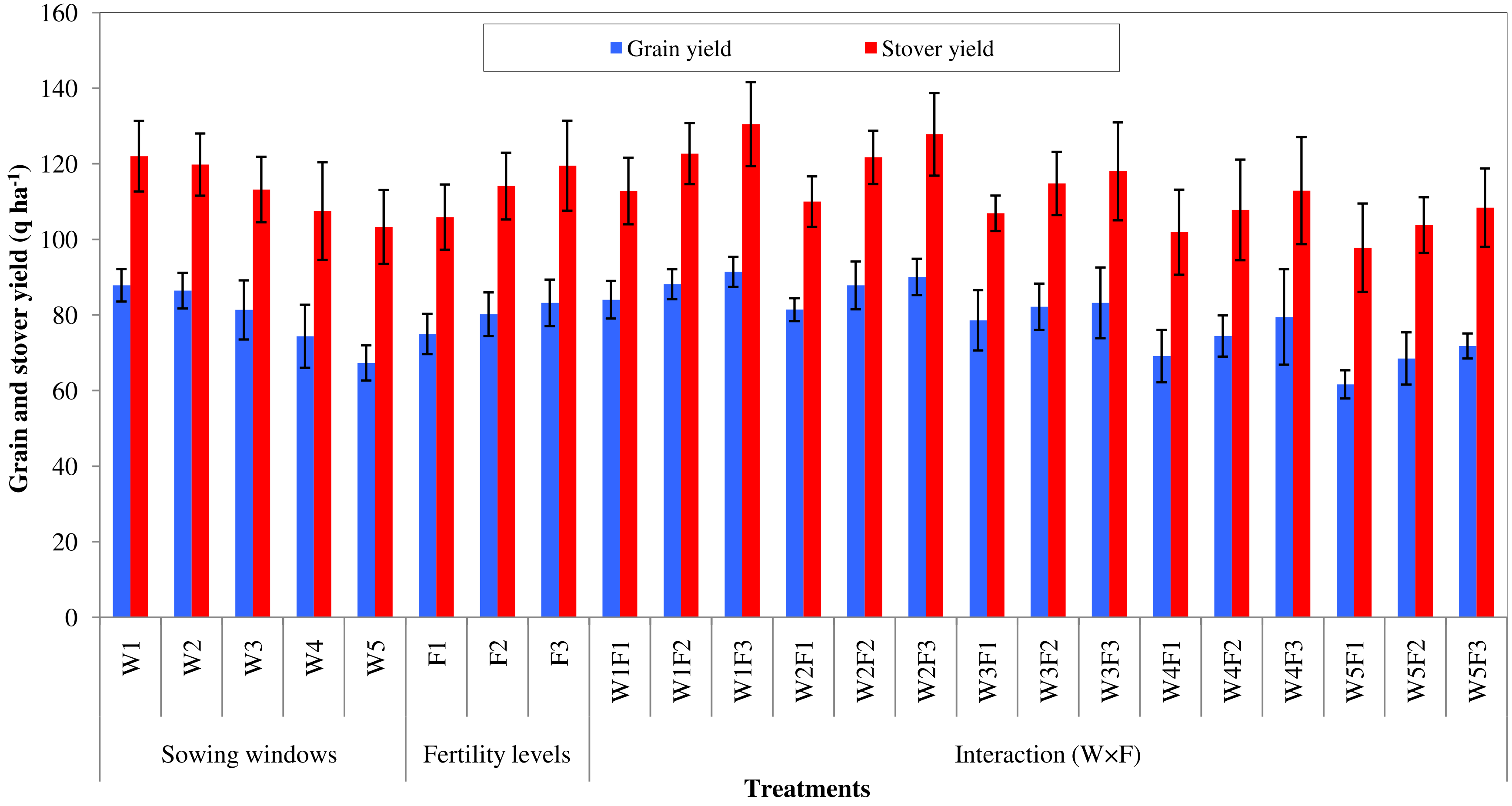


Figure 1c: TDM production per plant at different growth stages of winter maize as influenced by sowing windows and fertility levels



Factor I: Sowing windows

W_1: 1st week of October
W_2: 2nd week of October
W_3: 3rd week of October
W_4: 4th week of October
W_5: 1st week of November

Factor II: Fertility levels

F_1: 100 % RDF
F_2: 150% RDF
F_3: 200% RDF

Figure 2: Grain yield and stover yield of winter maize as influenced by sowing windows and fertility levels

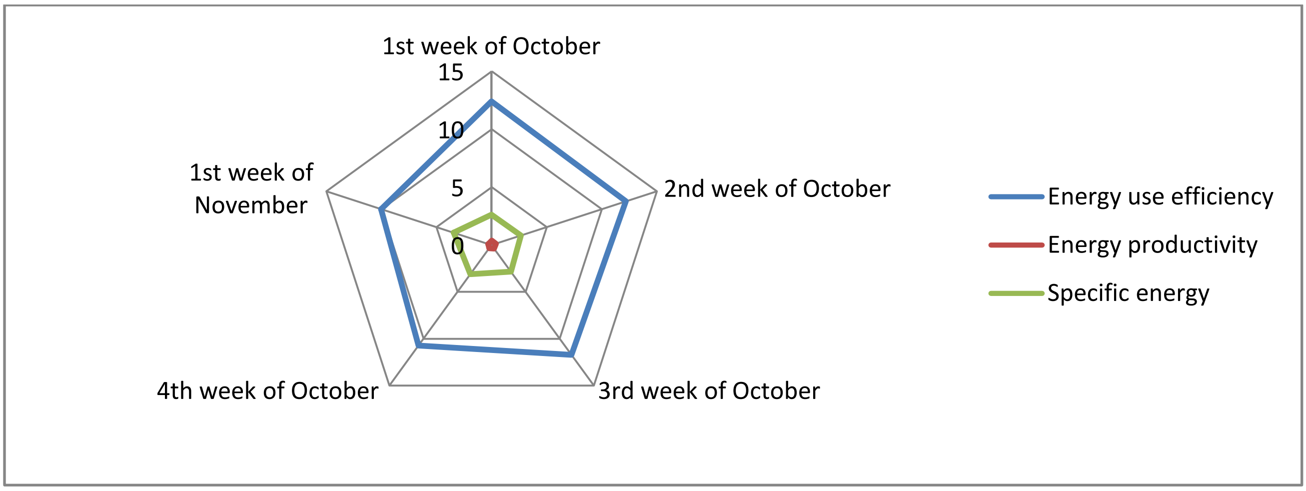


Figure 3a. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for 1st, 2nd, 3rd, 4th week of October and 1st week of November.

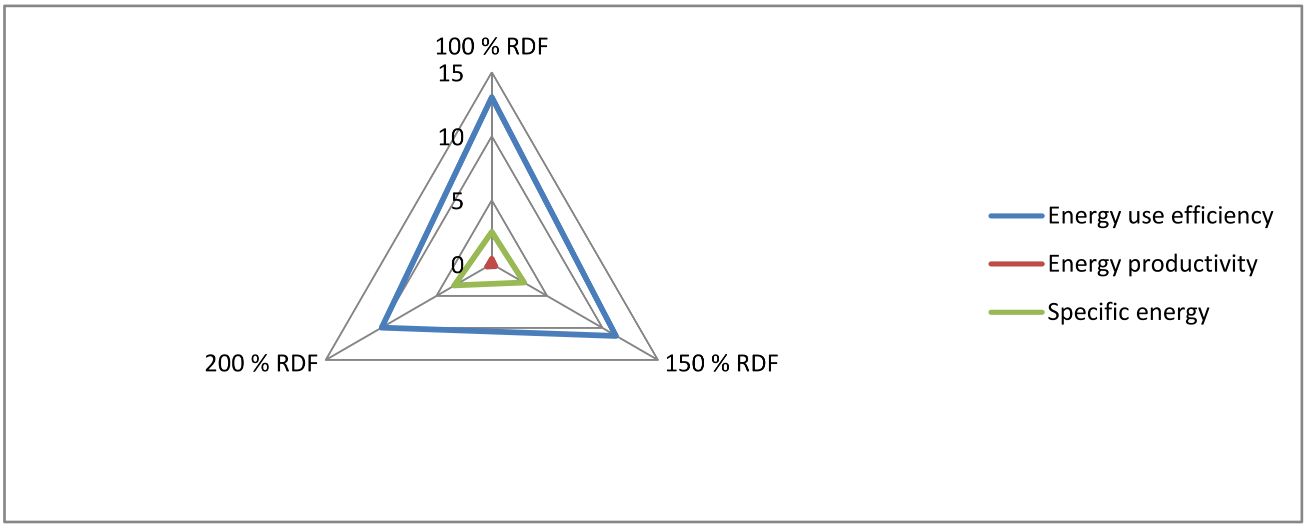


Figure 3b. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for 100 %, 150 % and 200 % RDF.

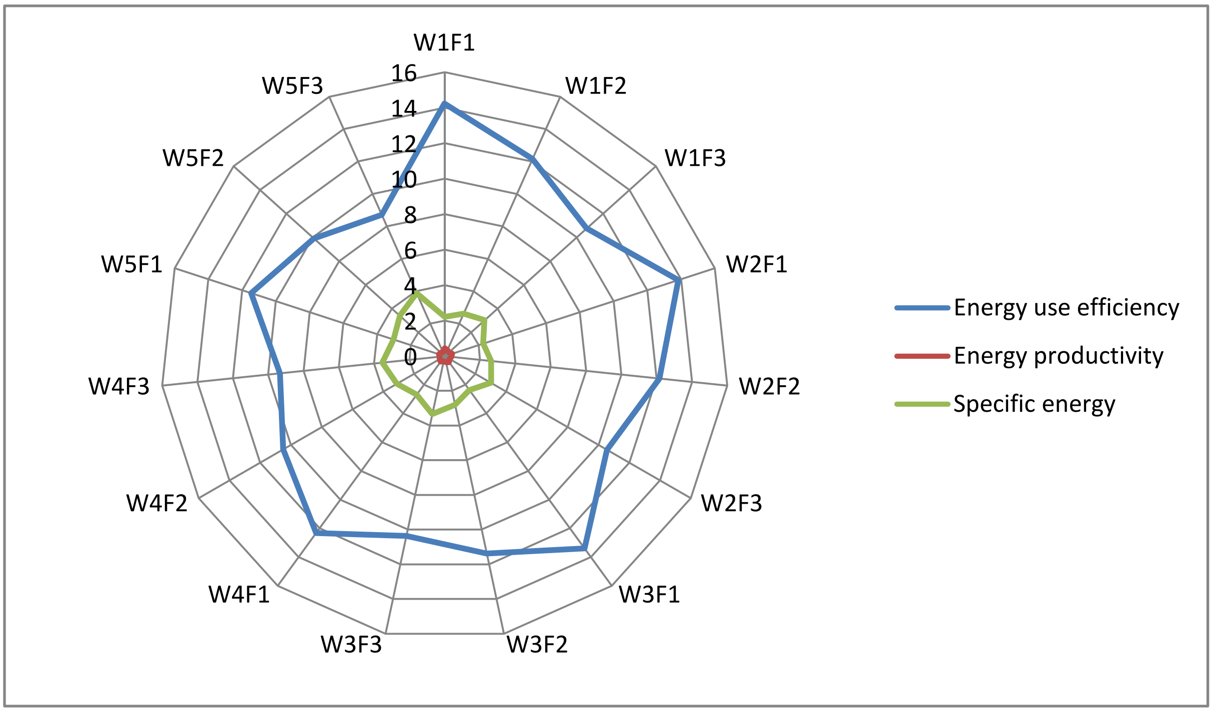


Figure 3c. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for treatment combinations (sowing windows and fertility levels).

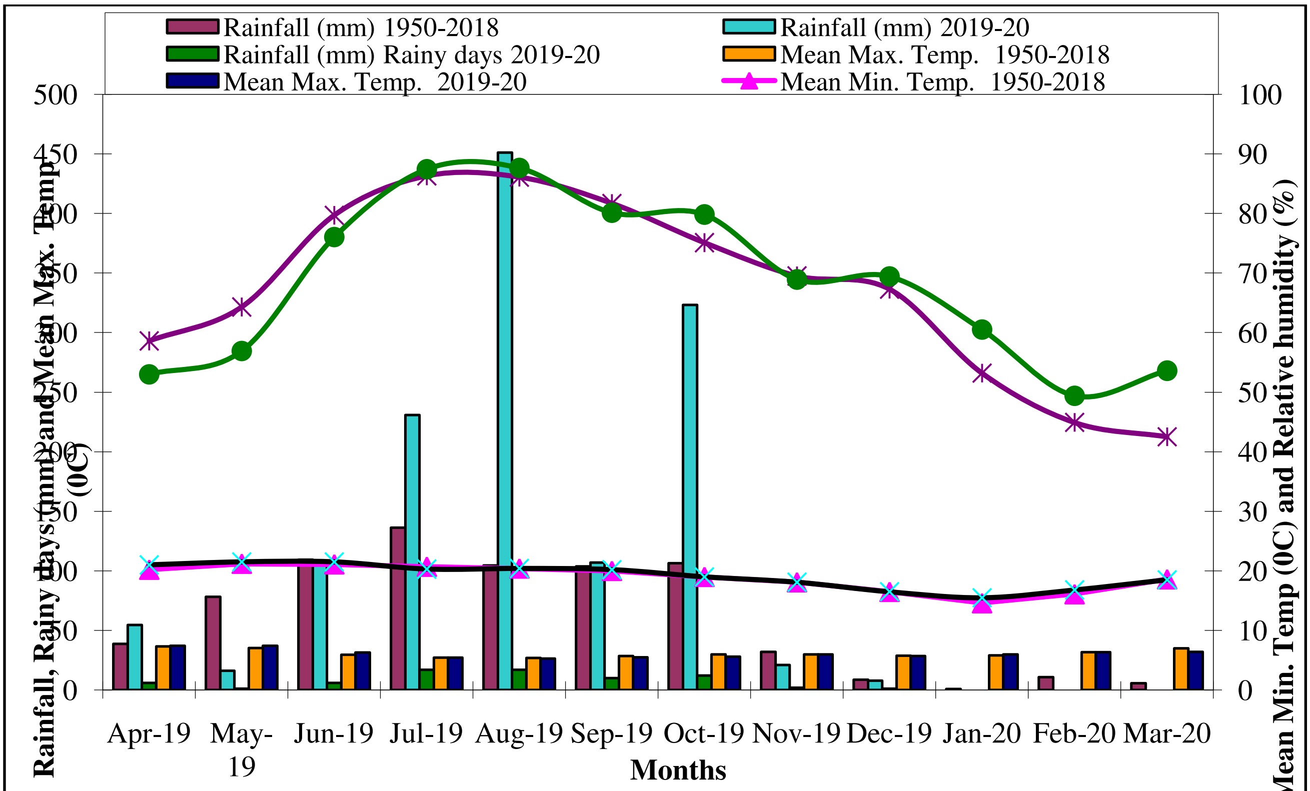


Fig. 4: Monthly meteorological data during crop growth period (2019-20) and the average of 69

Figures

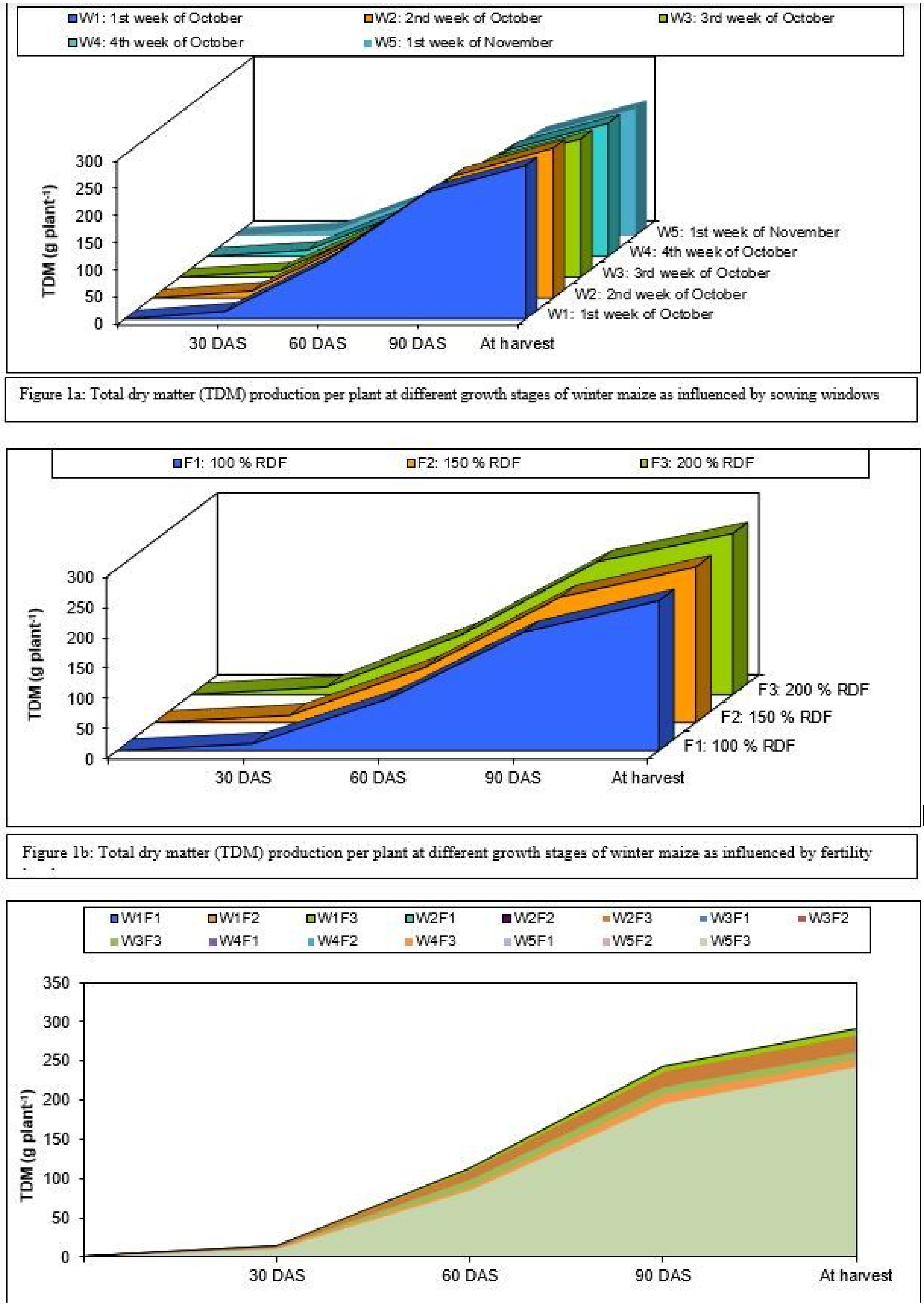


Figure 1a: Total dry matter (TDM) production per plant at different growth stages of winter maize as influenced by sowing windows

Figure 1b: Total dry matter (TDM) production per plant at different growth stages of winter maize as influenced by fertility

Figure 1

Figure 1a: Total dry matter (TDM) production per plant at different growth stages of winter maize as influenced by sowing windows. Figure 1b: Total dry matter (TDM) production per plant at different growth

stages of winter maize as influenced by fertility levels. Figure 1c: TDM production per plant at different growth stages of winter maize as influenced by sowing windows and fertility levels .

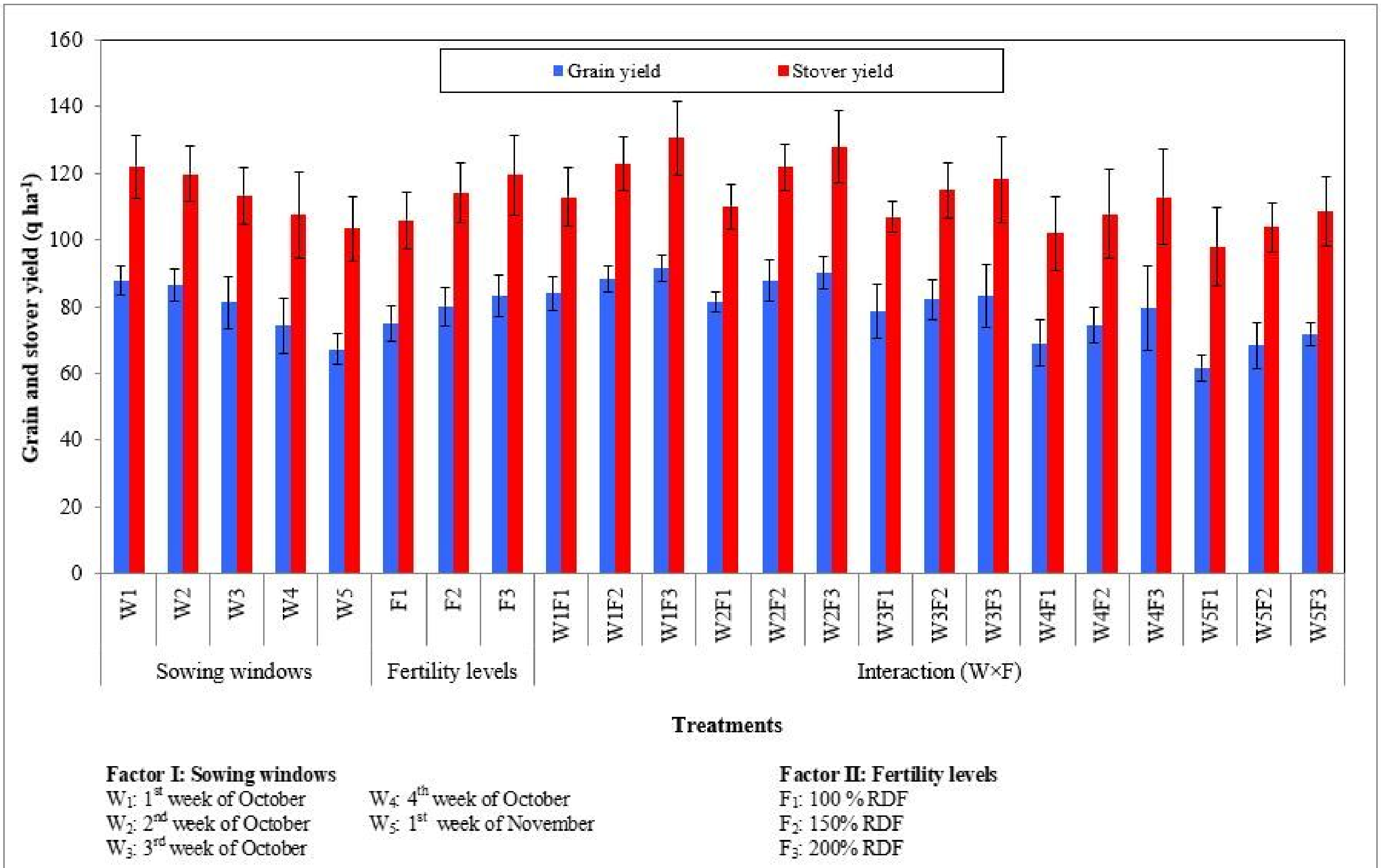


Figure 2: Grain yield and stover yield of winter maize as influenced by sowing windows and fertility levels

Figure 2

Grain yield and stover yield of winter maize as influenced by sowing windows and fertility levels

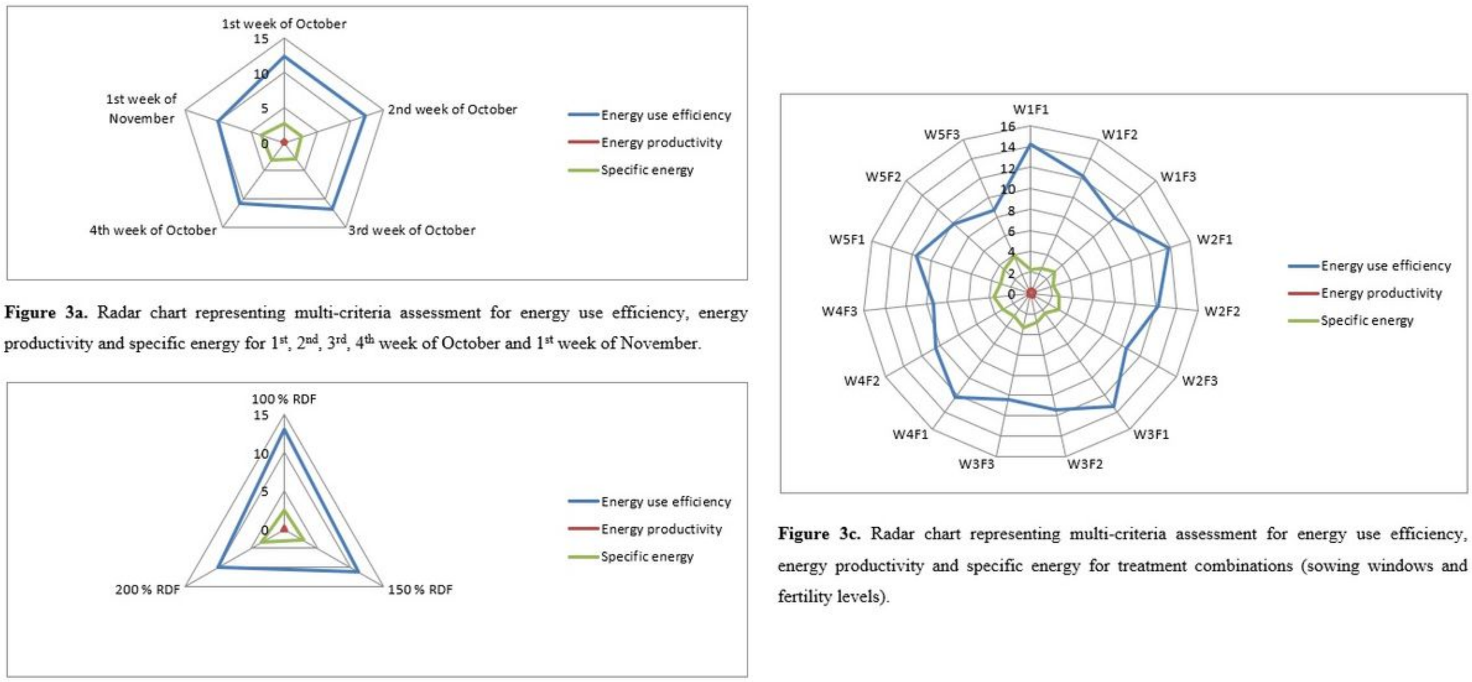


Figure 3a. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for 1st, 2nd, 3rd, 4th week of October and 1st week of November.

Figure 3b. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for 100 %, 150 % and 200 % RDF.

Figure 3c. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for treatment combinations (sowing windows and fertility levels).

Figure 3

Figure 3a. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for 1st, 2nd, 3rd, 4th week of October and 1st week of November. Figure 3b. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for 100 %, 150 % and 200 % RDF. Figure 3c. Radar chart representing multi-criteria assessment for energy use efficiency, energy productivity and specific energy for treatment combinations (sowing windows and fertility levels).

Supplementary Files

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- Tabelsrevised.docx