Optimal Strategy of Irrigation Amount and Combined Application of Organic Fertilizer could Improve Soil Microbial Biomass Carbon, Nitrogen and Enzyme Activities and Enhance Water and Fertilizer Productivity in Panax Notoginseng

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Optimal Strategy of Irrigation Amount and Combined Application of Organic Fertilizer could Improve Soil Microbial Biomass Carbon, Nitrogen and Enzyme Activities and Enhance Water and Fertilizer Productivity in *Panax Notoginseng*

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Abstract: *Panax pseudoginseng* growers, in pursuit of maximum yields and economic benefits, blindly increase irrigation water and excessive application of pesticides and chemical fertilizers, resulting in the accumulation of soil nutrients year by year, nutrient leaching loss, soil environmental quality and yield saponin content decline in the outstanding problems, the study provides technical support for the efficient use and management of *Panax pseudoginseng* water and fertilizers, and has important practical significance for high yield and quality planting of *Panax pseudoginseng*. In this paper, three irrigation levels of W1 (5.00 mm), W2 (10.00 mm), and W3 (15.00 mm) were set for *Panax pseudoginseng* at the root growth stage, seedling stage, flowering stage, and fruiting stage, and four organic fertilizer application levels of F1 (48.00 kg.hm^{-2}), F2 (72.00 kg.hm^{-2}), F3 (96.00 kg.hm^{-2}) and F4 (120.00 kg.hm^{-2}) were used for the study from 2018 to 2020 in Luxi County, Honghe Prefecture, Yunnan Province. F2 (72.00 kg.hm^{-2}), F3 (96.00 kg.hm^{-2}), and F4 (120.00 kg.hm^{-2}) were tested in the field with the optimal strategy. The results showed that the soil microbial biomass carbon and nitrogen content, soil urease, sucrase, acid phosphatase, and catalase activities differed significantly (p<0.05) at different fertility periods with the same irrigation rate and organic fertilizer application, and the soil microbiomes carbon and nitrogen content and enzyme activities had the characteristics of increasing first and then decreasing with the extension of fertility period and increasing with the increase of irrigation rate and fertilizer application. Soil acid phosphatase and catalase were the main microbial quantity carbon and nitrogen control factors, urease was the main microbial quantity carbon control factor and sucrase was the main microbial quantity nitrogen control factor, and there was no correlation between soil water content and microbial quantity carbon and nitrogen (p>0.05). The differences in yield, saponin content, water use efficiency, and fertilizer bias productivity of *Panax pseudoginseng* with different irrigation and organic fertilizer were highly significant (p<0.01), yield increased and then decreased with increasing irrigation and fertilizer application, water use efficiency decreased with increasing irrigation and increased with increasing fertilizer application, fertilizer bias productivity decreased with increasing fertilizer application and was highly significant (p<0.01) with irrigation, saponin The saponin content increased and then decreased with the increase of irrigation water, and decreased and then increased with the increase of fertilizer application. *Panax pseudoginseng* yield, saponin content, water use efficiency, and fertilizer utilization were the highest in W2F3 and W2F4 treatments and the lowest in CK treatment. The overall evaluation was that

the optimal irrigation amount was 10 mm and the fertilizer application rate was 120 kg.hm^{-2} at the root growth stage of *Panax pseudoginseng*, and the optimal irrigation amount was 15 mm and the fertilizer application rate was 120 kg.hm^{-2} at the seedling, flowering and fruiting stages, and both W2F3 and W2F4 treatments improved the carbon and nitrogen content and enzyme activity of soil microorganisms, which were conducive to improving yield quality and water and fertilizer productivity.

Keywords: *Panax pseudoginseng*, Optimal strategy of water and fertilizer, Microbial biomass of carbon and nitrogen, Soil enzyme activity, Water and fertilizer productivity.

1. Introduction

Soil microbial biomass (SMB) is the active component of soil organic matter, which has a key role in soil ecosystem regulation and functional modulation and is one of the biological indicators to evaluate the overall soil quality (Raiesi et al., 2015; Evangelou et al., 2021; Yang et al., 2018; Yu et al., 1999; Yi et al., 2010). Soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) determine soil fertility and are important sources of soil organic carbon and nitrogen (Yu et al., 1999; Zhou et al., 2002). Soil enzymes are derived from soil microorganisms, plant root secretions, soil fauna, and biological residues and are sensitive to different irrigation levels and organic fertilizer dosing (Yang et al.,2020). They are one of the most active components of the soil ecosystem (Luo et al., 2014; Hill et al., 2012) and play an important role in nutrient cycling such as nitrogen fixation, phosphorus adsorption, and potassium release, as well as in soil structure maintenance and crop yield (Burns et al., 2013; Zhao et al., 2016). They constitute a composite soil fertility bioindicator (Zhang et al., 2015; Lepcha et al., 2020). As a catalyst of soil organic matter decomposition and nutrient conversion cycle, soil enzymes are closely related to soil nutrient content and microbial load carbon and nitrogen (Wang et al., 2016; Li et al.,2014). Integrated soil fertility is determined by the soil microbial load of carbon and nitrogen as well as enzyme activity (Zhou.,2002; Zhu et al., 2017).

Fertilizer application and irrigation had highly significant effects on soil microbial biomass carbon, nitrogen and enzyme activities (Tang et al., 2019; Wang et al.,2016; Boerner et al., 2004). Studies on soil microbial characteristics, soil enzyme activity and nutrient regulation in water-saving irrigated winter wheat

showed that soil microbial characteristics and soil enzyme activity were highly significantly correlated with irrigation fertilization (p<0.01) and increased soil enzyme activity, which was closely related to soil C and N nutrient cycling and conversion (Wang et al., 2017; Calderon et al., 2016; Ye et al., 2016). Long-term N application was found to reconstruct the spatial patterns of soil MBC, MBN, and MBC: MBN compared to soils that had not been fertilized for many years (Li et al., 2018). A study on the effects of soil microbial quantity carbon and nitrogen in rice with different fertility stages under long-term fertilizer management found that different fertilizer management had different effects on soil organic carbon (SOC) content, soil microbial quantity carbon (SMBC), and soil microbial quantity nitrogen (SMBN), with 30% organic matter + 70% inorganic fertilizer (LOM), 60% organic matter + 40% inorganic fertilizer (HOM), and rice straw + inorganic fertilizer (RF) treatments having higher yields in both early and late rice than inorganic fertilizer alone (MF) and no fertilizer (CK) (Xu et al., 2018). After studying the effects of long-term application of inorganic and organic fertilizers on organic matter and microbial load of carbon and nitrogen in three subtropical rice soils, the results showed that inorganic fertilizers mixed with organic fertilizers and straw increased the organic matter and microbial load of subtropical rice soils (Hao et al., 2008). The microbial activity of fertilized grassland was studied to be higher than that of non-fertilized soil, and nitrogen fertilization of fertilized grassland enhanced soil microbial quantity of carbon and nitrogen and enzyme activity (Bach and Hofmockel, 2015).

There have been many studies on the effects of different irrigation rates and organic fertilizer dosing on SMBC, SMBN, and enzyme activities, but quantitative studies on the medicinal plant *Panax pseudoginseng* have not received much attention. Studies on the effects of fertilizer-irrigation interactions on *Panax pseudoginseng* root zone secretions, soil SMBC, SMBN, and enzyme activities are also scarce, thus affecting soil microbial traits in *Panax pseudoginseng* farmlands. At present, research on water-fertilizer interaction is mainly focused on regulating the improvement of saline soils in northern dryland farmlands and the quality of crop yield (Li et al., 2016; Zheng et al., 2020), while research on *Panax pseudoginseng* is mainly focused on single factors, cultivation patterns, continuous crop barriers of *Panax pseudoginseng*, accumulation and adsorption of heavy metals in soil and the ratio of fertilizer elements (Tang et al., 2020). Few studies were conducted to investigate the optimal strategy of different irrigation and organic fertilizer dosing on

soil microbial load carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization, and saponin content response of *Panax pseudoginseng*, SMBC, SMBN and enzyme activity that disturbed soil fertility (Boerner et al. 2004). In this study, a completely randomized combination experimental design was used to conduct experiments on the optimal strategy of different irrigation and organic fertilizer application using *Panax pseudoginseng* growth for three years from 2018 to 2020, and the responses of different irrigation and organic fertilizer application strategies on soil microbial carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization rate, and saponin content were analyzed. The results of the study can provide technical support for the efficient use and management of water and fertilizer in *Panax pseudoginseng* fields, and have important practical significance for guiding the cultivation of *Panax pseudoginseng* with high yield and quality.

2 Materials and methods

2.1 Experimental design and sample collection

This trial was conducted in 2018-2020 at a typical *Panax pseudoginseng* planting site in Luxi County, Honghe Prefecture, Yunnan Province, geographically located at 24°15′N, 103°30′E. The site has a northern subtropical monsoon climate. *Panax pseudoginseng* reproductive period is divided into root growth (November-January each year), seedling (February-April), flowering (May-July), and fruiting (August-October). Three irrigation water levels (W) and four organic fertilizer application levels (F) were designed according to the high-yielding and efficient irrigation and fertilization system of local *Panax pseudoginseng* cultivation, with three irrigation water levels were W1 (5.00 mm), W2 (10.00 mm) and W3 (15.00 mm), and four fertilizer application levels were F1 (48.00 $kg.hm^{-2}$), F2 (72.00 $kg.hm^{-2}$), F3 (96.00 $kg.hm^{-2}$) and F4 (120.00 $kg.hm^{-2}$), respectively. Thirteen trials with different irrigation amounts and optimal strategies for organic fertilizer allocation were set up by the completely randomized combination method, namely W1F1, W1F2, W1F3, W1F4, W2F1, W2F2, W2F3, W2F4, W3F1, W3F2, W3F3, W3F4 and CK, CK control treatment, CK was managed according to the traditional planting irrigation and fertilizer application scheme of local growers, and the experimental treatments are shown in Table 1. There were three replicates of each treatment, for a total of 39 sample plots, all of which were covered with 5 mm pine needles on the surface. Each

plot was 16.70 m long and 1.50 m wide. Before planting, a trench was opened and a monopoly was started, with a depth of 30 cm, a width of 40 cm at the bottom of the trench, and a spacing of 10 cm. Each plot is irrigated with upside-down micro-sprinklers, and the amount of irrigation is mainly controlled by water valves and water meters installed on the water pipes in the system. At the beginning of each growth period, the amount of irrigation water and organic fertilizer required for the different fertility stages of the different treatments were mixed and delivered to the pipes in each test area, and irrigation and fertilization were carried out simultaneously every half month. To avoid the effect of natural rainfall on the test, the experimental site was covered with a double layer of shade netting and plastic film. The fertilizer was Dermet water-soluble organic fertilizer with N≥21%, P_2O_5≥21%, K_2O≥21%, hemic acid ≥6%, Fe chelate ≥0.05%, Zn chelate ≥0.05%, Cu chelate ≥0.017%, Mn chelate ≥0.05%, B≥0.1%, Mo≥0.007%. Hg≤5 $mg.kg^{-1}$, As ≤10 $mg.kg^{-1}$, Cd≤10 $mg.kg^{-1}$, Cr≤50 $mg.kg^{-1}$, Pb≤50 $mg.kg^{-1}$, Cd≤10 $mg.kg^{-1}$, Cr≤50 $mg.kg^{-1}$, Pb≤50 $mg.kg^{-1}$.

Table 1. Experimental scheme of combined application with different irrigation amount and organic fertilizer amount

Treatments	Irrigation volume(mm)	Fertilizer application rate($kg.hm^{-2}$)
W1F1	5.00	48.00
W1F2	5.00	72.00
W1F3	5.00	96.00
W1F4	5.00	120.00
W2F1	10.00	48.00
W2F2	10.00	72.00
W2F3	10.00	96.00
W2F4	10.00	120.00
W3F1	15.00	48.00

W3F2	15.00	72.00
W3F3	15.00	96.00
W3F4	15.00	120.00
CK	Traditional planting irrigation and fertilization	

Sampling was conducted on the third day after irrigation and fertilization during the root increase (November-January of the following year), seedling (February-April), flowering (May-July), and fruiting (August-October) periods for each year from 2018-2020. During the sampling process, three 1 m×1 m sampling points were set in the middle and lower part of each plot, and the soil surface apoplast and gravel around the sampling points were removed, and the soil depths were 0-20 cm, 20-40 cm, and 40-60 cm. Soil samples were added to self-sealing bags labeled, sealed, stored, and brought back to the laboratory. The fresh soil samples were divided into two parts. One part was used to measure the microbial load carbon and nitrogen content, and the other part was spread on kraft paper to dry naturally, then roots, leaves, and gravel were removed, then ground and sieved to test soil enzyme activity. Taking Three *Panax pseudoginseng* plants in the upper, middle, and lower parts of each plot each year and brought back to the laboratory to measure yield and total saponin content. The basic physicochemical properties of the test soil are shown in Table 2.

Table 2. Basic physical and chemical properties of soil

Organic Carbon $g \cdot kg^{-1}$	Total Nitrogen $g \cdot kg^{-1}$	Total Potassium $g \cdot kg^{-1}$	Total Potassium $g \cdot kg^{-1}$	Available Potassium $mg \cdot kg^{-1}$	Nitrate Nitrogen $mg \cdot kg^{-1}$	Ammonium Nitrogen $mg \cdot kg^{-1}$	Available Potassium $mg \cdot kg^{-1}$	pH	Field Water-Holding Capacity %
14.33	0.98	0.37	14.79	316.8	8.35	19.15	11.65	6.34	36.93

2.2 Determination method

Soil microbial load of carbon and nitrogen was determined by the chloroform fumigation leaching method. Chloroform fumigated and unfumigated soils were extracted with 0.5 mol/L K_2SO_4 solution, and the soil-liquid ratio was 1:4 for chloroform fumigated and unfumigated soils. The organic carbon content in the extract was determined by titration with $FeSO_4$ solution with a conversion factor of 0.38, and the organic

nitrogen content in the extract was determined by the colorimetric method with ninhydrin with a conversion factor of 5.00 (Li et al., 2008). Analyze the three replicates of each fumigated and non-fumigated sample and calculate the mean. The $KMnO_4$ titration method was used to titrate until purple faded to light pink. The catalase activity was expressed by the milliliter of 0.1mol.L^{-1} $KMnO_4$ consumed per 1g.h^{-1} soil; Urease (Ure) was calculated using the phenol-sodium hypochlorite colorimetric method, and the results were calculated by measuring the absorbance values of the samples at 578 nm with a spectrophotometer, and the urease activity was expressed as milligrams of NH_3-N produced in 1 g of soil after 1 d of incubation; Sucrase (Sue) using the 3,5 dinitro salicylic acid colorimetric method, with sucrase activity expressed as milligrams of glucose produced in 1 g of soil after 1 d of incubation; Acid phosphatase (Acp) was expressed as milligrams of phenol released from 1g of soil after 1d using the colorimetric method of sodium benzene phosphate. *Panax pseudoginseng* yield was measured by weighing method and total saponin content was determined by high-performance liquid chromatography. Each soil and *Panax pseudoginseng* plant sample was measured at least three times and the average value was taken.

Yield(Y), Y was determined by weighing method, water use efficiency(WUE), and fertilizer partial productivity (PFP) were measured at the end of each year. Each index was measured three times each time and the average value was taken, WUE and PFP are calculated as follows:

$$WUE=Y/W$$

$$PFP=Y/F$$

where WUE represents the water use efficiency, kg·m^{-3}; Y represents the *Panax Notoginseng* yield, kg·hm^{-2}; W represents total irrigation, m^3·hm^{-2}; PFP represents partial fertilizer productivity, kg·kg^{-1}; F represents total fertilizer application, kg·hm^{-2}.

2.3 Comprehensive evaluation calculation

In this study, the entropy value method is used to determine the weights of various indicators, due to the differences among the indicators, to eliminate the influence of indicator data outline and positive and negative indicators, the raw data are standardized to form new data columns. The following formula is the entropy value method to calculate the index weights (Huang et al., 2021; Lu et al., 2019). Using the TOPSIS method, analyze SMBC, SMBN, and soil enzyme activities, which allows the quality to be assessed by cal-

culating the relative distance between the sample and the best or worst solution (Wu et al., 2014). Steps (1) and (2) are entropy methods for calculating index weights, and step (3) is the TOPSIS assessment calculation method:

Data standardization

$$u_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, \quad u_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, \tag{1}$$

where u_{ij} is the value of indicator j of its i sample (i = 1, 2, ..., n; j = 1, 2, ..., n); $\max(x_{ij})$ and $\min(x_{ij})$ are the maximum and minimum values of indicator x_{ij}, respectively, and u_{ij} is normalized x_{ij}, which are the standardized indicators of the soil microbial carbon and nitrogen contents and enzyme activity under different water and fertilizer optimal management regimes.

Calculate the weight of i sample data under j the indicator for that indicator a_{ij}:

$$a_{ij} = u_{ij} / \sum_{i=1}^{n} u_{ij} \tag{2}$$

TOPSIS evaluation method

①Construction of original evaluation matrix:

There are m evaluation objects and n evaluation indicators; the indicators and the corresponding entropy weights W_j are multiplied, and the data are represented as the original matrix $X = (X_{ij})_{m \times n}$, where X_{ij} is the original data of the jth indicator of the ith treatment:

$$Z_{ij=} \frac{X_{ij}}{\sqrt{\sum_{j=1}^{n} X_{ij}^2}} \tag{3}$$

where i = (1, 2, …, m), j = (1, 2, …, n), and m = 13, i.e., the 13 water and fertilizer treatment trials. n = 6 indicators of the soil enzyme activities and microbial biomass carbon and nitrogen.

②Normalization matrix $Z = (Z_{ij})_{m \times n}$. The maximum and minimum values of each column constitute the optimal and inferior vectors, respectively:

$$Z^{+} = (Z_{\max 1},\ Z_{\max 2},\cdots,\ Z_{\max n})$$
$$Z^{-} = (Z_{\min 1},\ Z_{\min 2},\cdots,\ Z_{\min n}) \quad (4)$$

210 ③The distances between the ith treatment and the optimal and inferior solutions are:

$$D_i^{+} = \sqrt{\sum_{j=1}^{n}(Z_{\max_j} - Z_{ij})^2}$$
$$D_i^{-} = \sqrt{\sum_{j=1}^{n}(Z_{\min_j} - Z_{ij})^2} \quad (5)$$

211 ④The ith treatment fits the optimal solution Ci are:

$$C_i = \frac{D_i^{-}}{(D_i^{+} + D_i^{-})} \quad (6)$$

212 2.4 Statistical analysis

213 Microsoft Excel 2021 and SPSS26.0 were used for the statistical analysis of the data, and a one-way
214 ANOVA was used to test the differences in the soil microbial biomass carbon and nitrogen contents and en-
215 zyme activity under different water and fertilizer optimal management regimes (α = 0.05). The entropy
216 method was used to calculate the weight and rank the soil microbial biomass carbon and nitrogen contents
217 and enzyme activity. Mantel analysis was performed using the R language, and Origin2020b software was
218 used for mapping.

219 3 Result and Analysis

220 3.1 Characteristics of soil microbial biomass carbon and nitrogen

221 The soil microbial carbon and nitrogen content varied significantly (p<0.05) among fertility periods
222 with the same irrigation and organic fertilizer application, and tended to increase and then decrease with in-
223 creasing fertility time, in descending order of flowering, fruiting, seedling, and root growth stages. Table 3
224 shows that the highest levels of SMBC and SMBN were found in the flowering stage with 1.06 g·kg^{-1} and
225 66.22 g·kg^{-1}, respectively, and the lowest in the root growth stage with 0.39 g·kg^{-1} and 14.99 g·kg^{-1}. The
226 SMBC content increased with the prolongation of the *Panax pseudoginseng* growth period from high to low
227 in the order of flowering, fruiting, seedling, and root-boosting stages. The SMBN content increased by

12.44% and 37.86% from the root-boosting stage to the flowering stage, in the order of flowering, fruiting, seedling, and root-boosting stages, respectively. The maximum SMBC content of W3F4 treatment was 1.06 $g \cdot kg^{-1}$, which was 34.18%, 24.71%, and 16.48% higher than the root growth, seedling and fruiting stages, respectively; the maximum difference between flowering and rooting stages was 0.27 $g \cdot kg^{-1}$. The SMBN content reached a maximum of 66.21 $mg \cdot kg^{-1}$ at the flowering stage of W3F4, which was 48.41%, 29.49%, and 15.47% higher than that at the rooting, seedling, and fruiting stages, respectively. The maximum difference between the flowering and rooting stages of W3F4 was 21.60 $mg \cdot kg^{-1}$. SMBC and SMBN contents under W3F4 treatment showed the greatest variation over the four reproductive stages and the most stable carbon-to-nitrogen ratio. It showed that W3F4 was more effective in regulating soil microbial biomass carbon and nitrogen content. There were significant differences in soil microbial biomass carbon and nitrogen contents with different water and fertilizer management at the same fertility period, and SMBC and SMBN contents increased with the increase of irrigation water and fertilizer application. The SMBC and SMBN contents of W3F4 were greater than those of other treatments at all fertility stages. W1F1 had the lowest SMBC content at all fertility stages except CK, and W3F4 increased 29.63 $mg \cdot kg^{-1}$ over W1F1 at the root increase stage, which was 2.37 times higher than CK. At the seedling stage, W3F4 increased 33.81 $mg \cdot kg^{-1}$ over W1F1, which was 2.47 times higher than CK. At anthesis, W3F4 increased 39.52 $mg \cdot kg^{-1}$ compared with W1F1, which was 2.23 times higher than that of CK. At the fruiting stage, W3F4 increased 37.17 $mg \cdot kg^{-1}$ compared with W1F1, which was 2.48 times higher than that under CK. W3F4 treatment significantly increased SMBC and SMBN contents in all four reproductive stages.

249 **Table 3. Characteristics of the changes in the soil microbial biomass carbon and nitrogen**

Growth Period	SMBC SMBN	W1F1	W1F2	W1F3	W1F4	W2F1	W2F2	W2F3	W2F4	W3F1	W3F2	W3F3	W3F4	CK	*p*
Rooting period	SMBC g·kg^{-1}	0.50±0.03Ld	0.56±0.07Kd	0.65±0.06Fd	0.70±0.05Dd	0.56±0.04Jd	0.59±0.05Id	0.64±0.05Hd	0.67±0.03Ed	0.65±0.04Gd	0.75±0.04Cd	0.79±0.04Bd	0.79±0.04Ad	0.39±0.04Md	0.000**
	SMBN mg·kg^{-1}	14.99±1.19Md	18.97±1.27Kd	23.35±1.30Id	28.43±1.27Fd	22.76±1.22Jd	25.73±1.25Hd	30.26±1.35Ed	36.01±1.43Bd	27.27±1.24Gd	31.12±1.26Dd	35.12±1.39Cd	44.62±1.41Ad	18.86±1.16Ld	0.000**
Seeling period	SMBC g·kg	0.55±0.05Lc	0.65±0.05Ic	0.70±0.03Gc	0.75±0.04Ec	0.59±0.02Kc	0.63±0.03Jc	0.71±0.04Fc	0.70±0.05Dc	0.70±0.03Hc	0.79±0.03Cc	0.83±0.04Bc	0.85±0.04Ac	0.44±0.03Mc	0.000**

od	$^{-1}$													
	SM													
	BN	17.33±1.	21.47±1	30.01±1	31.15±1	26.41±1	31.48±1	33.44±1	40.81±1	31.72±1	35.31±1	38.48±1	51.14±1	20.74±1	0.0
	mg·	25Mc	.24Kc	.35Ic	.36Hc	.24Jc	.33Gc	.34Ec	.36Bc	.37Fc	.34Dc	.35Cc	.39Ac	.22Lc	00
	kg^{-1}														**
	SM														
	BC	0.64±0.0	0.71±0.	0.76±0.	0.83±0.	0.70±0.	0.73±0.	0.79±0.	0.85±0.	0.80±0.	0.89±0.	0.97±0.	1.06±0.	0.64±0.	0.0
Flow	g·kg	3La	04Ja	04Ha	04Ea	03Ka	03Ia	04Ga	04Da	03Fa	03Ca	03Ba	04Aa	03Ma	00
ering	$^{-1}$														**
peri-	SM														
od	BN	26.70±1.	33.26±1	41.30±1	46.25±1	32.00±1	36.35±1	41.20±1	55.15±1	45.70±1	50.15±1	55.79±1	66.22±1	29.74±1	0.0
	mg·	35Ma	.38Ja	.35Ha	.37Ea	.26Ka	.35Ia	.36Ga	.41Ca	.36Fa	.34Da	.39Ba	.37Aa	.26La	00
	kg^{-1}														**
Fruiti	SM														
ng	BC	0.60±0.0	0.65±0.	0.73±0.	0.75±0.	0.63±0.	0.69±0.	0.76±0.	0.81±0.	0.75±0.	0.85±0.	0.86±0.	0.91±0.	0.49±0.	0.0
peri-	g·kg	3Lb	02Jb	03Hb	03Fb	04Kb	02Ib	03Eb	04Db	03Gb	04Cb	03Bb	04Ab	03Mb	00
od	$^{-1}$														**

SM BN mg·kg^{-1}	20.18±1.38Mb	24.47±1.35Kb	31.57±1.37Ib	40.58±1.26Eb	28.82±1.35Jb	33.79±1.36Hb	37.97±1.24Fb	42.70±1.33Cb	36.94±1.34Gb	41.18±1.24Db	50.65±1.34Bb	57.35±1.37Ab	23.10±1.26Lb	0.000**

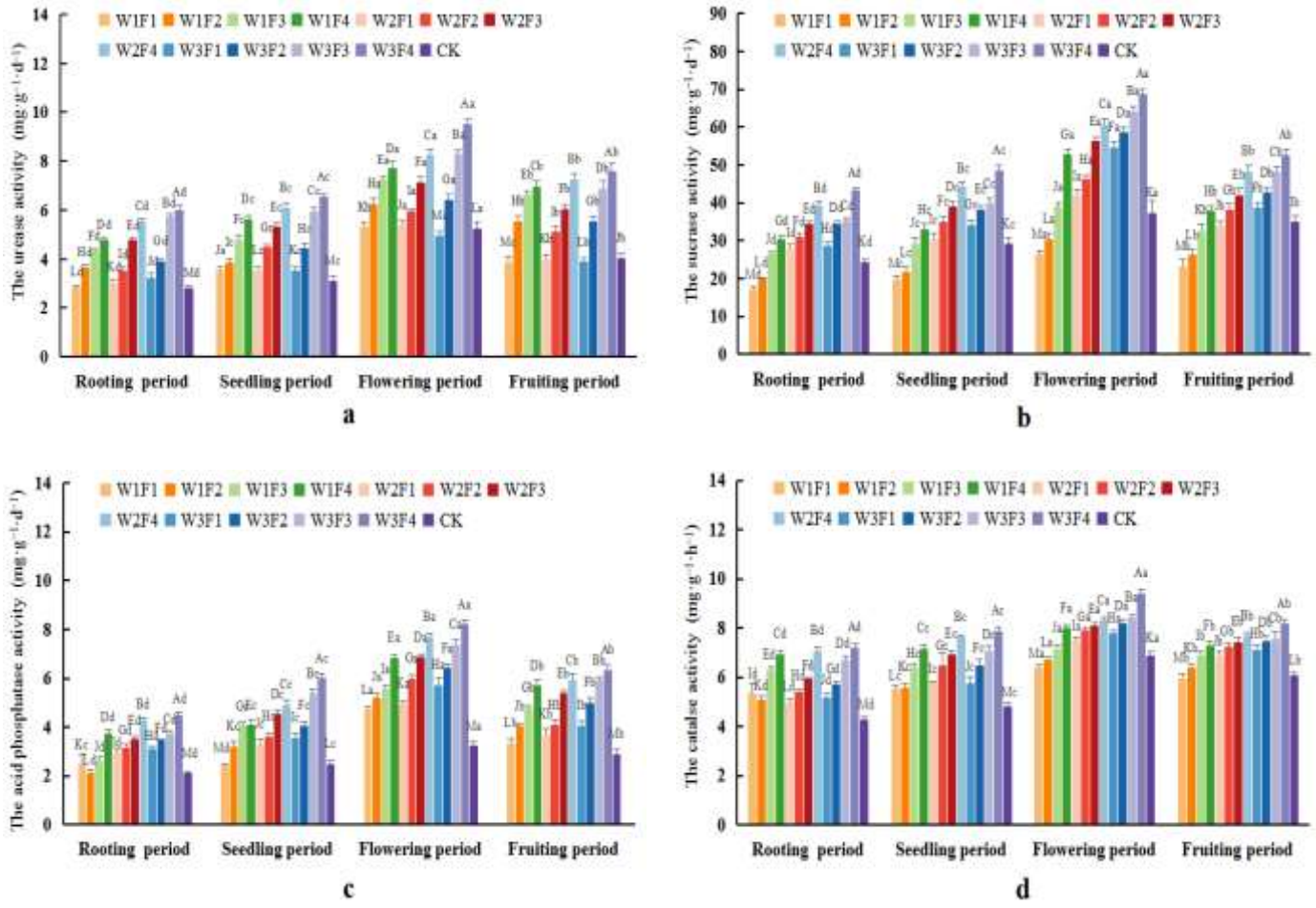
Note 1: W1F1, W1F2, W1F3, etc. are the 13 treatments designed in this experiment.

Note 2: Different capital letters indicate significant differences between different water and fertilizer control treatments in the same growth period ($p< 0.05$) and different lowercase letters indicate significant differences between different growth periods under the same water and fertilizer control treatment ($p< 0.05$).

Note 3: ** indicate significant difference at 0.01 levels.

256 3.2 Change characteristics of soil enzyme activity

257 Soil urease, sucrase, acid phosphatase, and catalase activities differed significantly (p<0.05) at differ-
258 ent fertility stages with the same irrigation rate and organic fertilizer, and the enzyme activities increased
259 and then decreased with the extension of the fertility period; the enzyme activities at the root growth stage
260 were 1.67 times higher than those at CK under W3F4, and 1.35 times higher than those at the flowering
261 stage, and the soil urease, sucrase, acid phosphatase, and catalase activities differed significantly (p<0.05) at
262 the same fertility stage with different irrigation rates and organic fertilizer, Acid phosphatase, and catalase
263 activities differed significantly (p<0.05) at the same fertility period with different irrigation and organic fer-
264 tilizer. Soil urease, sucrase, acid phosphatase, and peroxidase activities increased with increasing irrigation
265 and fertilizer application. As can be seen from Figure 1, catalase activity ranged from 5.1-9.42 $mg \cdot kg^{-1} \cdot h^{-1}$
266 and urease activity ranged from 2.86-9.52 $mg \cdot kg^{-1} \cdot d^{-1}$, with an increase of 30.81% and 46.08% from root
267 growth to flowering stage, respectively, and W3F4 was 2.14-fold higher than under CK at root growth stage
268 and 1.82-fold higher at flowering stage. The sucrase activity ranged from 17.12-68.79 $mg \cdot kg^{-1} \cdot d^{-1}$ and in-
269 creased by 31.94% and 44.43% from root growth to flowering stage, respectively; W3F4 root growth activ-
270 ity was 1.78 times higher than that under CK and 1.83 times higher than flowering stage activity. Acid
271 phosphatase activity ranged from 2.14-8.2 $mg \cdot kg^{-1} \cdot d^{-1}$ and increased by 34.08% and 59.01% from root
272 growth to the flowering stage, respectively, with 2.10-fold higher activity at the root growth stage and
273 2.53-fold higher activity at flowering stage under W3F4 than CK. Soil urease, sucrase, acid phosphatase,
274 and catalase activities under W3F4 were highest at the flowering stage and increased by 44.26%, 61.51%,
275 42.56%, and 32.25%, respectively, compared to the minimum values under W1F1, indicating that W3F4
276 treatment significantly increased soil enzyme activities.



277 **Fig. 1. Characteristics of the changes in the soil enzyme activity**

278 Note 1: W1F1, W1F2, W1F3, etc. are the 13 treatments designed in this experiment.

279 Note 2: Different capital letters indicate significant differences between the different water and fertilizer
280 control treatments in the same growth period (p<0.05) and different lowercase letters indicate significant
281 differences between the different growth periods under the same water and fertilizer control treatments (p<
282 0.05).

283 Note 3: (a) Urease activity; (b) Sucrase activity; (c) Acid phosphatase activity; (d) Catalase activity.

284 3.3 Effects of soil microbial biomass carbon and nitrogen on enzyme activities

285 Mantel analysis was used to test 1000 permutations of the relationship between soil microbial load
286 carbon and nitrogen and soil enzyme activity and water content at different irrigation and organic fertilizer
287 doses to derive correlation and explanatory values (Figure 2a). The results showed that the least significant
288 values of Mantel for soil acid phosphatase (Acp), catalase (Cat) and microbial carbon (Mantel's p<0.01), the
289 least significant values of Mantel for soil sucrase (Sue), acid phosphatase (Acp) and catalase and microbial

nitrogen (Mantel 's p<0.01), while Mantel's significant values for sucrase on soil microbiomass carbon were less than 0.05 and for urease on soil microbiomass carbon and nitrogen were less than 0.05; The maximum explained values of acid phosphatase and catalase on microbial load carbon and nitrogen (Mantel's r≥0.5) indicate that the level of soil acid phosphatase and catalase content is the main influencing factor regulating microbial load carbon and nitrogen, while the maximum explained values of sucrase on microbial load nitrogen (Mantel's r≥0.5), indicating that the level of soil sucrase content was the main influencing factor in regulating microbial quantity nitrogen, while the Mantel's significant and explanatory values for urease and microbial quantity carbon were (Mantel's p<0.05, Mantel's r=0.25-0.5), which was an important factor affecting microbial quantity carbon. Soil water content and microbial load carbon and nitrogen Mantel's significant and explained values were (Mantel's p>0.05, Mantel's r<0.25), indicating that soil water content has a small effect on microbial load carbon and nitrogen.

The results in Figure 2b show that there are different levels of correlation between soil enzyme activity and microbial carbon and nitrogen. The correlation coefficients of soil acid phosphatase and catalase on microbial carbon and nitrogen ranged from (0.90-1.00), indicating a highly significant positive correlation (p<0.01) between the above factors and soil microbial carbon and nitrogen, which is consistent with the results of 2a. The correlation coefficients of urease and sucrase on microbial carbon and nitrogen ranged from (0.80-0.95), indicating a significant positive correlation (p<0.05) between the above factors and soil microbial load carbon and nitrogen. There was no correlation between soil water content and microbial carbon and nitrogen (p>0.05).

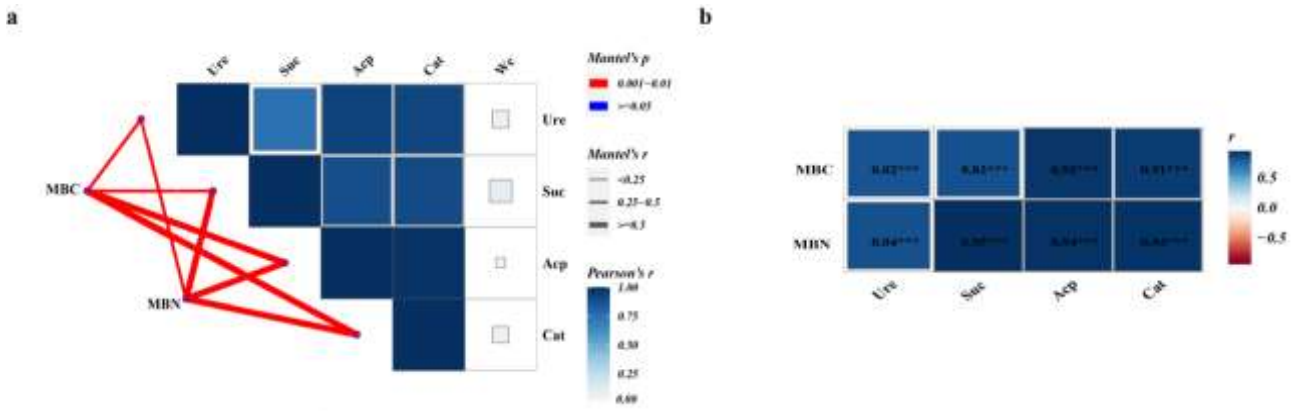


Figure 2. Mantel analysis of the soil enzyme activity with the soil micro biomass carbon, nitrogen, and their ratios.

Note 1: MBC is microbial biomass carbon, MBN is microbial biomass nitrogen, Ure is soil urease, Suc is soil sucrase, Acp is soil acid phosphatase, and Cat is soil catalase.

Note 2: (a) Mantel analysis; (b) Correlation between SMBC, SMBN, and enzyme activities.

Note 3: *** indicates a significant correlation at the 0.001 level.

3.4 Effect of Water and fertilizer productivity

As can be seen from Table 4, the differences in *Panax pseudoginseng* yield, saponin content, water use efficiency, and fertilizer bias productivity were highly significant (p<0.01) for different irrigation and organic fertilizer doses, highly significant (p<0.01) for different irrigation yields, saponin content and fertilizer bias productivity and significant (p<0.05) for water use efficiency, and different fertilizer applications yield, saponin content, water use efficiency, and fertilizer bias The differences in yield, saponin content, water use efficiency, and fertilizer bias productivity were highly significant (p<0.01). W2F3 and W2F4 *Panax pseudoginseng* yielded the largest with 2618.24 and 2797.25 kg·hm^{-2}, respectively, followed by W1F3, W1F4, W3F3 and W3F4 *Panax pseudoginseng* yields, and CK yielded the smallest with 1026.32 kg·hm^{-2}. The water use efficiency of W2F3 and W2F4 *Panax pseudoginseng* was the largest with 1.21 and 1.29 kg·m^{-3}, respectively, followed by W1F3, W1F4, W3F3, and W3F4, and the smallest with 0.47 kg·m^{-3} for CK. The fertilizer bias productivity of W2F3 and W2F4 *Panax pseudoginseng* was the largest with 1.82 and 1.94 kg·kg^{-1}, respectively, and the smallest with 0.71 kg-kg-1 for W1F3, W1F4, W3F3, and W3F4. W1F3, W1F4, W3F3, and W3F4 had the next highest fertilizer bias productivity, and CK had the lowest fertilizer bias productivity of 0.71 kg·kg^{-1}. *Panax pseudoginseng* yield increased and then decreased with the increase of irrigation and fertilizer application, water use efficiency decreased with the increase of irrigation and increased with the increase of fertilizer application, fertilizer bias productivity decreased with the increase of fertilizer application, and the difference with irrigation was highly significant (p<0.01). Significant differences (p<0.05) in *Panax pseudoginseng* saponin content were found between different irrigation and organic fertilizer doses. The saponin content of *Panax pseudoginseng* increased and then decreased with the increase

of irrigation amount, and the saponin content of *Panax pseudoginseng* decreased and then increased with the increase of irrigation amount, and the saponin content of W2F3 and W2F4 treatments were the largest, 164.86 and 176.34 $mg \cdot kg^{-1}$, respectively, and the saponin content of CK treatment was the smallest, 96.32 $mg \cdot kg^{-1}$.

Table 4. Effects of yield, saponins, and water and fertilizer productivity

Treatment	Yield $kg \cdot hm^{-2}$	WUE $kg \cdot m^{-3}$	PFP $kg \cdot kg^{-1}$	Total Saponin $mg \cdot kg^{-1}$
W1F1	1569.93±0.21d	0.73±0.18b	1.09±0.17e	133.44±0.61bc
W1F2	1763.52±0.32d	0.81±0.21a	1.22±0.12de	119.62±0.47bc
W1F3	2354.12±0.12bc	1.09±0.31ab	1.63±0.14abc	146.66±0.31cd
W1F4	2396.44±0.63cd	1.11±0.24ab	1.66±0.16bcd	162.88±0.46cd
W2F1	2011.23±0.89cd	0.93±0.23ab	1.40±0.23cde	148.4±0.52b
W2F2	2031.45±0.75ab	0.94±0.17b	1.41±0.24cde	132.82±0.61b
W2F3	2618.24±0.89a	1.21±0.15ab	1.82±0.31ab	164.86±0.43cd
W2F4	2797.25±0.75cd	1.29±0.23a	1.94±0.21a	176.34±0.87d
W3F1	1916.33±0.42cd	0.89±0.03c	1.33±0.26cde	114.09±0.38bc
W3F2	2061.22±0.81cd	0.95±0.11ab	1.43±0.27bcd	103.9±0.76bc
W3F3	2339.68±0.65bc	1.08±0.04cd	1.62±0.23abc	121.95±0.34cd
W3F4	2321.96±0.23bc	1.07±0.02ab	1.61±0.28bcd	127.18±0.23cd
CK	1026.32±0.24e	0.47±0.01e	0.71±0.37e	96.32±0.12e
W	**	*	**	**
F	**	**	**	**
W×F	**	**	**	**

Note 1: W1F1, W1F2, W1F3, etc. are the 13 treatments designed in this experiment. Note 2: Different lowercase letters indicate significant differences between yield, water use efficiency, fertilizer partial productivity, and total saponin under the different water and fertilizer control treatment ($p<0.05$)

Note 3: * indicates significant positively correlation, (p<0.05) ** indicates very significant positively correlation (p<0.01)

3.5 Comprehensive impact assessment

To comprehensively and systematically reflect the effects of different irrigation and organic fertilizer applications on soil microbial carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization, and saponin content of *Panax pseudoginseng*, and to avoid the problem of difficulty in evaluating the quality of water and fertilizer management due to many test indicators, the entropy value method combined with TOPSIS method was used to evaluate soil microbial carbon and nitrogen, enzyme activity, yield, fertilizer utilization, and saponin content at different fertility stages under different irrigation and organic fertilizer applications, The entropy method combined with TOPSIS method was used to evaluate the carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization and saponin content of soil microorganisms at different fertility stages under different irrigation and organic fertilization. The method can determine the ranking of soil microbial biomass carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization, saponin content fit Ci, and its optimal solution under different irrigation and organic fertilizer rations, to find the best water and fertilizer management system for different fertility periods. The larger the Ci value of the optimal solution fit, the better the microbial biomass carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization, and saponin content of *Panax pseudoginseng* soil. As shown in Table 5, the Ci values were F4, F3, F2, and F1 in descending order under the same irrigation treatment. the Ci values decreased and then increased with increasing irrigation amount for the same fertilization treatment, in descending order for W2, W1, and W3. The highest Ci value at the root growth stage was 0.836 for the W2F4 treatment, followed by the W3F4 treatment at 0.794, and the lowest for the W1F2 and W1F1 treatments at 0.214 and 0.133. The maximum Ci value at the seedling stage was 0.806 for W3F4, followed by W2F4 at 0.801. The lowest Ci values were 0.263 and 0.111 for the W1F2 and W1F1 treatments, respectively. W3F4 treatment had the highest Ci value of 0.733, which was lower than the W2F3 treatment Ci value of 0.568. W2F1 and W1F1 treatments had the lowest Ci values of 0.216 and 0.189, respectively. W2F1 and W1F1 were the worst, with Ci values of 0.273 and 0.068, respectively.

based on the best Ci analysis of soil microbial quantity of carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization, and saponin content at different irrigation and organic fertilizer doses, W2F4 treatment was the best at the root growth stage, and W3F4 was the best at the seedling, flowering and fruiting stages.

Table 5. Comprehensive impact assessment

Treatment	Rooting Period					Seedling Period					Flowering Period					Fruiting Period				
	Weight W_j	Positive Ideal Solution Distance D_i^-	Negative Ideal Solution Distance D_i^+	Relative Proximity C_i	Rank	Weight W_j	Positive Ideal Solution Distance D_i^-	Negative Ideal Solution Distance D_i^+	Relative Proximity C_i	Rank	Weight W_j	Positive Ideal Solution Distance D_i^-	Negative Ideal Solution Distance D_i^+	Relative Proximity C_i	Rank	Weight W_j	Positive Ideal Solution Distance D_i^-	Negative Ideal Solution Distance D_i^+	Relative Proximity C_i	Rank
W1F1	0.074	0.366	0.056	0.133	13	0.075	0.361	0.045	0.111	13	0.076	0.348	0.081	0.189	13	0.076	0.358	0.026	0.068	13
W1F2	0.076	0.323	0.088	0.214	12	0.078	0.296	0.106	0.263	12	0.077	0.282	0.153	0.353	9	0.077	0.267	0.123	0.316	11
W1F3	0.078	0.249	0.166	0.400	8	0.078	0.225	0.168	0.428	8	0.077	0.287	0.131	0.312	10	0.077	0.204	0.193	0.486	7
W1F4	0.078	0.144	0.267	0.651	4	0.078	0.185	0.221	0.545	5	0.076	0.191	0.207	0.522	5	0.076	0.168	0.237	0.585	5
W2F1	0.075	0.296	0.126	0.299	10	0.075	0.279	0.122	0.304	10	0.076	0.316	0.087	0.216	12	0.075	0.284	0.106	0.273	12
W2F2	0.074	0.268	0.139	0.342	9	0.074	0.235	0.158	0.402	9	0.075	0.304	0.111	0.267	11	0.075	0.229	0.146	0.389	9

W2F3	0.075	0.157	0.240	0.605	5	0.075	0.148	0.242	0.621	4	0.075	0.183	0.241	0.568	2	0.076	0.148	0.225	0.603	4
W2F4	0.075	0.066	0.336	0.836	1	0.074	0.081	0.319	0.801	2	0.074	0.188	0.238	0.559	3	0.076	0.094	0.290	0.755	3
W3F1	0.078	0.262	0.185	0.414	7	0.077	0.246	0.195	0.443	7	0.076	0.235	0.244	0.509	6	0.077	0.249	0.182	0.422	8
W3F2	0.079	0.197	0.219	0.526	6	0.078	0.215	0.191	0.472	6	0.077	0.239	0.191	0.443	7	0.078	0.158	0.219	0.581	6
W3F3	0.079	0.092	0.316	0.774	3	0.078	0.132	0.282	0.681	3	0.077	0.217	0.259	0.544	4	0.077	0.089	0.293	0.766	2
W3F4	0.077	0.097	0.374	0.794	2	0.076	0.087	0.362	0.806	1	0.077	0.126	0.346	0.733	1	0.077	0.069	0.353	0.835	1
CK	0.068	0.358	0.109	0.233	11	0.069	0.337	0.126	0.272	11	0.074	0.311	0.199	0.392	8	0.070	0.306	0.151	0.332	10

4 Discussion

4.1 Effect mechanism on soil microbial biomass carbon and nitrogen

In this study, significant differences (p<0.05) were found between soil microbial carbon and nitrogen at different fertility stages with the same amount of irrigation and organic fertilizer application, and the trend was to increase and then decrease with time. The soil microbial carbon and nitrogen contents were in descending order of flowering, fruiting, seedling, and root growth stages, with the highest in the flowering stage (rainy season) and the lowest in the root growth stage (dry season). In the study, it was found that different forest stand types showed significant seasonal variations in microbial carbon, with minimum values in winter and maximum values in the rainy season (Bargali et al., 2018); in the study on the effect of land use types and seasonal variations on soil microbial carbon and nitrogen in the eastern Himalaya, it was found that different land use types showed strong seasonal differences in soil microbial carbon and nitrogen (p<0.001), with the highest values occurring in the rainy season and the lowest values in winter (Lepcha et al., 2020). These findings are consistent with the trend of the results of this study, leading to the highest soil microbial biomass carbon and nitrogen content during the flowering period (rainy season) and the lowest during the root increase period (dry season) in this study, due to the separation of dry and wet seasons in the study area, rainy in summer and dry in winter and spring, abundant rainfall, moist air and low evaporation in summer, soil temperature and humidity suitable for the growth, reproduction, and decomposition activities of soil microorganisms, which increase microorganisms and promote the transformation and accumulation of soil microbial biomass carbon and nitrogen content. In the irrigation water-season interaction study, these factors were found to have significant effects on soil microbial respiration, SMBC, and SMBN, and increasing water-season interaction had significant effects on MR, MBC, and MBN, with MR, MBC, and MBN significantly higher in summer and autumn and no effect in spring and winter (Huang et al., 2021). Bacterial biomass as well as bacterial and fungal diversity and abundance increased with irrigation in summer and autumn, contrary to the results of Li. Due to the different climate types in the two regions, soil microbial biomass carbon and nitrogen in Mediterranean agroecosystems was lowest in summer and highest in autumn,

with hot and dry summers and warm and rainy winters in the Mediterranean region, in contrast to the rainy summers and dry winters and springs in the studied region.

In this study, it was found that SMBC, SMBN, and enzyme activities differed significantly (p<0.05) between different irrigation and organic fertilizer applications at the same fertility period, and soil microbial biomass carbon and nitrogen content increased with irrigation and fertilizer application, indicating that long-term fertilizer application increased soil microbial biomass carbon and dehydrogenase activity. The organic fertilizer had a greater effect on SMBC and dehydrogenase activity than the mineral fertilizer because it increased soil organic matter content and improved soil physicochemical properties compared to mineral fertilizer (Luo et al., 2015). The increase in the lower soil elemental and microbial biomass stoichiometry SMBC: SMBP (soil microbial phosphorus) and SMBN: SMBP and LAP (leucine aminopeptidase) was mainly due to irrigation and combined use of organic fertilizers and materials, which accelerated SOC and N mineralization (Yang et al., 2015). The results of the Ci comparison showed that W2F4 was the optimal treatment at the root-boosting stage, W3F4 at the seedling, flowering, and fruiting stages; W1F1 treatment was the least effective in regulating soil microbial load carbon and nitrogen at all fertility stages, W1F2 treatment was not suitable for the root-boosting and seedling stages, and W2F1 treatment was not effective at the flowering and fruiting stages. The results indicated that 5 mm irrigation and 48.00 kg.hm^{-2} fertilizer were not suitable for regulating SMBC, SMBN, and enzyme activities during *Panax pseudoginseng* fertility.

4.2 Effect mechanism on soil enzyme activity

Soil enzymes are key components that catalyze the breakdown of soil nutrients and their activity in the soil can be used as a measure of soil health (Ashraf et al., 2020; Kotroczo et al., 2014). In this study, we found that soil urease, sucrase, acid phosphatase, and catalase activities differed significantly (p<0.05) between fertility stages with the same amount of irrigation and organic fertilizer, and showed a trend of increasing and then decreasing with the fertility stage of *Panax pseudoginseng*, in descending order of flowering, fruiting, seedling, and root growth stages. This is similar to previous studies which found that soil enzyme activity has obvious seasonal characteristics(Pei et al., 2018), with soil sucrase activity showing summer > autumn > spring > winter and seasonal dynamics of urease activity showing summer > spring > au-

tumn > winter, with both soil enzyme activities being highest in summer and lowest in winter. It was reported in the report that soil enzyme activity of the reed community has obvious seasonal change characteristics, the peak value of soil catalase, phosphatase, and urease of the reed community appeared in the growth period, and the valley value appeared in the shrinkage period and leaf development period (Zhu et al., 2017), the flowering period of *Panax pseudoginseng* in this study was summer, and the growth was vigorous, the root increase period was winter, for the root increase period, the soil enzyme activity of *Panax pseudoginseng* was highest in the flowering period and lowest in the root increase period, the reason for this was the abundant rainfall in the rainy season, the soil temperature and humidity was suitable for microbial growth and reproduction, the soil enzyme activity increased with the microbial activity.

It was found that soil urease, sucrase, acid phosphatase, and peroxidase showed significant differences (p<0.05) at the same fertility period for different irrigation and organic fertilizer rations. Soil urease, sucrase, acid phosphatase, and catalase contents increased with irrigation and fertilizer application, and W3F4 treatment had the highest soil urease, sucrase, acid phosphatase, and catalase activities at the flowering stage. Soil enzyme activity W3F4 was the optimal treatment for all fertility stages, while W1F1 treatment was the least suitable for improving the soil enzyme activity of *Panax pseudoginseng*.

4.3 Effect mechanism of water and fertilizer interaction on water and fertilizer productivity

Water and fertilizer coupling can achieve reasonable coordination of irrigation and fertilization in a time quantity pattern according to the water and fertilizer demand of the crop growth cycle (Li et al., 2020). It is also believed that fertilizer application affects soil enzyme activity by improving soil physical and chemical properties and microbial communities, and that appropriate water-fertilizer ratios to improve soil fertility and crop yield have important effects (Vepsalainen et al., 2001). Proper irrigation can improve soil enzyme activity. Too much or too little soil water is not conducive to soil microbial growth and reproduction, resulting in lower soil enzyme activity. In this study, we found that the distribution characteristics of SMBC, SMBN, and enzyme activity were different at different irrigation and organic fertilizer doses, and SMBC and SMBN were highly significantly and positively correlated with soil enzyme activity (p<0.05), soil acid phosphatase and catalase were highly significantly and positively correlated with SMBC and SMBN

(p<0.01), and urease was highly significantly and positively correlated with SMBC and SMBN (p<0.05). This is similar to the results of previous studies (Eivazi et al.,1996). Soil urease, sucrase, and acid phosphatase activities had highly significant positive correlations with SMBC, SMBN, and phosphorus. This is because soil enzyme activities are mainly derived from soil microorganisms, plant root secretions, and soil animals, and a closer relationship exists between soil enzyme activities and soil microbial load. A highly significant positive correlation between soil microbial load C, N, and P, and soil urease, sucrase, and alkaline phosphatase activities was found in the study (Yang et al., 2020). Soil convertase, acid phosphatase, and catalase were the main factors affecting SMBC and SMBN regulation, and urease activity affected SMBC and SMBN regulation important factors. In this experiment, W2F4 treatment at the root increase stage had the best effect on the regulation of SMBC, SMBN, and enzyme activity, which is the same as the previous study concluded (Tang et al.,2019) that the enzyme activity of pepper soil was highest when the soil water content was 62.0% of the field water holding capacity. w2 ranked second in the regulation effect at the seedling and flowering stage, and W3 ranked in the top two at the fruiting stage, where W3F4 was the most suitable treatment at the seedling, flowering, and fruiting stage. It was followed by W2F4, W2F3, and W3F3. W2F3 and W2F4 had the highest *Panax pseudoginseng* yield of 2618.24 and 2797.25 kg·hm^{-2}, respectively, and the highest water use efficiency of 1.21 and 1.29 kg·m^{-3} for W2F3 and W2F4, the highest fertilizer bias productivity of 1.82 and 1.94 kg·kg^{-1} for W2F3 and W2F4, respectively, and the highest saponin content of 164.86 and 176.34 mg·kg^{-1} for W2F3 and W2F4, respectively. W2F3 and W2F4 had the highest saponin content of 164.86 and 176.34 mg·kg^{-1}, respectively, and the CK treatment had the lowest yield, saponin content, water use efficiency, and fertilizer bias.

5 Conclusions

The response of soil microbial biomass carbon and nitrogen, enzyme activity, yield, water use efficiency, fertilizer utilization, and saponin content by different irrigation water and optimal strategy of organic fertilizer allocation. The main findings were as follows:

(1)The soil microbial carbon and nitrogen content differed significantly (p<0.05) between different fertility periods of *Panax pseudoginseng* with the same irrigation and organic fertilizer application, and showed

a trend of increasing and then decreasing with the increase of fertility time. microbial biomass carbon and nitrogen declined with decreasing irrigation and fertilizer application; The difference between different irrigation water and organic fertilizer application of soil microbial quantity carbon and nitrogen in the same fertility period was significant (p<0.05), and increased with the increase of irrigation water and fertilizer application, and W3F4 treatment was greater than other treatments in the same fertility period, and W3F4 treatment was favorable to microbial quantity carbon and nitrogen accumulation.

(2)SMBC and SMBN were highly significantly correlated with soil enzyme activity (p<0.05); The correlation coefficients of acid phosphatase and catalase with SMBC and SMBN were in the range of 0.90-1.00, urease and sucrase with SMBC and SMBN were in the range of 0.80-0.95, and soil microbial load carbon and nitrogen content influenced soil enzyme activity at optimal irrigation and organic fertilizer rationing strategies.

(3)Significant differences (p<0.05) in *Panax pseudoginseng* yield, saponin content, water use efficiency, and fertilizer bias productivity were observed between different irrigation and organic fertilizer treatments, with W2F3 and W2F4 *Panax pseudoginseng* yield, saponin content, water use efficiency and fertilizer bias productivity being the largest and CK treatment yield, saponin content, water use efficiency and fertilizer bias productivity being the smallest. The optimal irrigation rate of 10 mm and fertilizer application rate of 120 kg.hm^{-2} at the root growth stage and 15 mm and 120 kg.hm^{-2} at the seedling, flowering, and fruiting stages can improve soil microbial quantity of carbon, nitrogen, and enzyme activities, which are conducive to yield quality and water and fertilizer use efficiency.

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Data Availability Statement: Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

References

Ashraf,M.N.,Hu,C.,Wu,L.,et al.(2020).Soil and microbial biomass stoichiometry regulate soil organic carbon and nitrogen mineralization in rice-wheat rotation subjected to long-term fertilization.J.Soils Sediments.20,3103–3113.doi:10.1007/s11368-020-02642-y

Burns,R.G.,Deforest,J.L.,Marxsen,J.,et al.(2013).Soil enzymes in a changing environment:Current knowledge and future directions.Soil Biol.Biochem.58,216-234.doi: 10.1016/j.soilbio.2012.11.009

Bach,E.M.,Hofmockel,K.S.(2015).Coupled carbon and nitrogen inputs increase microbial biomass and activity in prairie bioenergy systems.Ecosystems.18,417-427. https://www.springer.com/journal/10021

Boerner,R.E.J.,Brinkman,J.A.,Smith,A.(2004).Seasonal variations in enzyme activity and organic carbon in soil of a burned and unburned hardwood forest.Soil Biol.Biochem.37,1419–1426.doi:10.1016/j.soilbio.2004.12.012

Bargali,K.,Manral,V.,Padalia,K.,et al.(2018).Upadhyay,V.P.Effect of vegetation type and season on microbial biomass carbon in Central Himalayan Forest soils,India.Catena,171,125-135.doi:10.1016/j. catena.2018.07.001

Calderon F.J.,Nielsen,D.,Acosta-Martinez,V.,et al.(2016).Cover crop and irrigation effects on soil microbial communities and enzymes in semiarid agroecosystems of the Central Great Plains of North America.Pedosphere,26,192–205.doi: 10.1016/S1002-0160(15)60034-0

Devi,N.B.,Yadava,P.S.(2006).Seasonal dynamics in soil microbial biomass C,N and P in a mixed-oak forest ecosystem of Manipur,Northeast India.Appl.Soil Ecol.31,220–227.doi:10.1016/j.apsoil.2005.05.005

Eivazi,F.,Bayan,M.R.(1996).Effects of long-term prescribed burning on the activity of select soil enzymes in an oak-hickory forest.Can.J.For.Res.26,1799–1804.doi:10.1139/x26-204

Hill,B.H.,Elonen C.M.,Seifert,L.R.,et al.(2012).Microbial enzyme stoichiometry and nutrient limitation in US streams and rivers.Ecol.Indic.18,540–555.doi:10.1016/j.ecolind.2012.01.007

Hao,X.H.,Liu,S.L.,Wu,J.S.,et al.(2008).Effect of long-term application of inorganic fertilizer and organic amendments on soil organic matter and microbial biomass in three subtropical paddy soils.Nutr.Cycl. Agroecosystems.81,17–24.doi:10.1007/s10705-007-9145-z

Huang,W.,Zhang,Y.,Yu, Y.,et al.(2021).Historical data-driven risk assessment of railway dangerous goods transportation system:Comparisons between Entropy Weight Method and Scatter Degree Method.Reliab. Eng.Syst.Saf.205,207–236.doi:10.1016/j.ress.2020.107236

Huang,G.,Li,L.,Su,Y.G.,et al.(2018).Differential seasonal effects of water addition and nitrogen fertilization on microbial biomass and diversity in a temperate de sert.Catena.161,27-36.doi:10.1016/j. catena.2017. 09. 03030

Kotroczó,Z.,Veres,Z.,Fekete,I.,et al.(2014).Soil enzyme activity in response to long-term organic matter manipulation.Soil Biol.Biochem.70,237–243.doi:10.1016/j.soilbio.2013.12.028

Luo,H.,Liu,S.,Li,F.S.(2014).Effect of different irrigation and fertilization strategies on soil microbial biomass carbon and nitrogen and enzyme activity.Acta Ecol.Sin.34,5266–5274.doi:10.5846/stxb201405090925

Li,J.P.,Wang,Z.M.,Zhang,Q.,et al.(2016).Effect of Micro-sprinkling Irrigation and Nitrogen Application Rate on Grain Filling and Nitrogen Uptake and Utilization in Winter Wheat.Acta Agric.Boreali Sin.31,1-10. doi:10.7668/hbnxb.2016.S1.001

Lu,J.P.,Wei,C.,Wu,J.,et al.(2019).TOPSIS method for probabilistic linguistic MAGDM with entropy weight and its application to supplier selection of new agricultural machinery products.Entropy.21,953–976.doi:10.3390/e21100953

Lepcha,N.T.,Devi,N.B.(2020).Effect of land use, season,and soil depth on soil microbial biomass carbon of Eastern Himalayas.Ecol.Process.9,65.doi:10.1016/j.apsoil.2020.02.006

Li,S.L.,Fang,X.,Xiang,W.H.,et al.(2014).Soil microbial biomass carbon and nitrogen concentrations in four subtropical forests in hilly region of central Hunan Province,China.Sci.Silvae Sin.50,8–16.doi:10. 11707/j.1001-7488.20140502

555 Luo,P.,Han,X.,Wang,Y.,et al.(2015).Influence of long-term fertilization on soil microbial bio-
556 mass,dehydrogenase activity,and bacterial and fungal community structure in a brown soil of northeast Chi-
557 na.Ann.Microbiol.65,533–542.doi:10.1007/s13213-014-0889-9
558 Li,J.M.,Yu,X.M.,Wang,X.W.,et al.(2020).Optimization of fertigation scheduling for drip-irrigated water-
559 melon based on its yield,quality and fertilizer and water use efficiency.Trans.CSAE,36,75–
560 83.doi:10.11975/j.issn.1002-6819.2020.09.009
561 Pei,B.,Zhu,L.F.,Feng,Z.P.,et al.(2018).Dynamics of soil enzyme activities under five different ages of
562 platycladus orientalis artificial forest in the southern taihang mountains.Res.Soil Water Conserv.25,170–
563 175+182.doi:10.13869/j.cnki.rswc.2018.02.024
564 Raiesi,F.,Beheshti,A.(2015).Microbiological indicators of soil quality and degradation following conversion
565 of native forests to continuous croplands.Ecol.Indic.50,173–185.doi:10.1016/j.ecolind.2014.11.008
566 Tang,J.K.,Han,H.H.,Liu,B.,et al.(2020).Effects of irrigation frequency and fertilization amount on active in-
567 gredient accumulation and morbidity of *Panax pseudoginseng*.Trans.Chin.Soc.Agric.Eng.36,55–63.doi:
568 10.11975/j.issn.1002-6819.2020.24.007
569 Tang,H.L.,Gong,W.,Wang,J.Y.,et al.(2019).Coupling effects of water and fertilizer on growth and enzyme
570 activities in soil of Zanthoxylum armatum seedling.J.Gansu Agric.Univ.2019,54,150–157.Doi:10.13432/j.
571 cnki.jgsau.2019.01.021
572 Vepsäläinen,M.,Kukkonen,S.,Vestberg,M.,et al.(2001).Application of soil enzyme activity test kit in a field
573 experiment.Soil Biol.Biochem.33,1665–1672.doi:10.1016/S0038-0717(01)00087-6
574 Wang,W.F.,Li,C.H.,Huang,S.W.,et al.(2016).Effects of different fertilization patterns on soil enzyme activi-
575 ties in greenhouse vegetable field.Chin.J.Appl.Ecol.27,873–882.doi:10.13287/j.1001-9332.201603.015
576 Wang,J.W.,Niu,W.Q.,Dyck,M.,et al.(2017).Drip irrigation with film covering improves soil enzymes and
577 muskmelon growth in the greenhouse.Soil Res.56,59–70.doi:10.1071/SR17036
578 Wu,X.,Wang,K.Y.,Niu,X.L.,et al.(2014).Construction of comprehensive nutritional quality index for tomato
579 and its response to water and fertilizer supply.Trans.CSAE.30,119–127.doi:10.3969/j.issn.1002-6819.
580 2014.07.014

581 Xu,Y.,Tang,H.,Xiao,X.,et al.(2018).Effects of long-term fertilization management practices on soil microbi-
582 al carbon and microbial biomass in paddy soil at various periods of rice growth.Agron.J.2017,109,1183–
583 1198.doi:10.1590/18069657rbcs20170111
584 Yu,S.,Li,Y.,Wang,J.H.,et al.(1999).Study on the soil microbial biomass as a bioindicator of soil quality in
585 the red earth ecosystem.Acta Pedol.Sin.36,413–422.doi:10.11766/trxb199708060316
586 Yang,X.D.,Zeng,X.B.,Wen,J.,et al.(2020).Effects of application of pig manure on physicochemical proper-
587 ties and enzyme activities of red soil upland.Acta Pedol.Sin.57,739–749.doi:10.11766/trxb201811230589
588 Ye,D.L.,Qi,R.J.,Zhang,M.C.,et al.(2016).Study of saving irrigation regulated the soil microbial characteris-
589 tics,soil enzyme activities and soil nutrient in the winter wheat field.Acta Agric.Boreali Sin.31,224–231.doi:
590 10.7668/hbnxb.2016.01.036
591 Yang,J.J.,An,S.S.,Zhang,H.(2015).Effect of erosion on soil microbial biomas and enzyme activity in the
592 Loes Hils.Acta Ecol.Sin.35,5666–5674.doi:10.1007/s003740000205
593 Yi,H.Y.,Gong,Y.B.,Wu,W.H.,et al.(2010).Efects of mountain forests-arid valley ecotone in the upper reach
594 of minjiang river vegetation restoration on soil microbial biomass and soil enzyme.J.Soil Water Conserv.24,
595 145–149.doi:10.13870/j.cnki.stbcxb.2010.03.029
596 Zhou,J.B.,Li,S.H.,Chen,Z.J.(2002).Soil microbial biomass nitrogen and its relationship to uptake of nitrogen
597 by plants.Pedosphere.12,251–256.doi:10.1007/s11769-002-0038-4
598 Zhang,X.Y.,Dong,W.Y.,Dai,X.Q.,et al.(2015).Responses of absolute and specific soil enzyme activities to
599 long term additions of organic and mineral fertilizer.Sci.Total Environ.,536,59–67.doi:10.1016/j.scitotenv.
600 2015.07.043
601 Zheng,M.J.,Zhang,L.H.,Dong,Z.Q.,et al.(2020).Effects of micro sprinkling irrigation on yield and water use
602 efficiency in summer maize.J.Nucl.Agric.Sci.34,839–848.doi:10.11869/j.issn.100-8551.2020.04.0839
603 Zhu,H.Q.,Li,Y.H.,Li,F.D.(2017).Seasonal variations of soil enzyme activities in typical plant communities
604 in the Ebinur Lake wetland,China.Chin.J.Appl.Ecol.28,1145–1154.doi:10.13287/j.1001-9332.201704.040