

# Potential of Hybrid CNN-RF Model for Early Crop Mapping with Limited Input Data

Geun-Ho Kwak, Chan-won Park, Kyung-do Lee, Sang-il Na, Ho-yong Ahn and No-Wook Park \*

**Table S1.** Optimal hyper-parameter values determined for combination cases of different training data sizes and the lengths of time-series in Anbandegi ( $p$  is the number of input variables).

Model	Hyper-parameter (layer description)	Optimal hyper-parameters (T1/T2/T3/T4/T5)
CNN and CNN-RF	Image patch size	5 × 5
	Convolution layer 1	A1: 128 / 256 / 256 / 128 / 128
		A2: 64 / 256 / 256 / 256 / 128
		A3: 128 / 128 / 256 / 256 / 256
	Convolution layer 2	A4: 128 / 128 / 128 / 64 / 256
		A5: 128 / 256 / 128 / 64 / 128
		A6: 64 / 256 / 128 / 64 / 128
	Convolution layer 3	A7: 64 / 128 / 64 / 256 / 64
		A8: 64 / 64 / 128 / 64 / 64
	Dropout	A1: 0.7 / 0.5 / 0.5 / 0.3 / 0.7
		A2: 0.5 / 0.5 / 0.5 / 0.3 / 0.7
		A3: 0.5 / 0.5 / 0.3 / 0.5 / 0.3
		A4: 0.3 / 0.3 / 0.5 / 0.3 / 0.3
		A5: 0.7 / 0.3 / 0.5 / 0.3 / 0.3
		A6: 0.3 / 0.5 / 0.5 / 0.5 / 0.5
		A7: 0.5 / 0.7 / 0.3 / 0.7 / 0.7
		A8: 0.3 / 0.5 / 0.3 / 0.7 / 0.3
		A1: 0.005 / 0.001 / 0.0005 / 0.0005 / 0.005
		A2: 0.0005 / 0.0001 / 0.0005 / 0.005 / 0.0005
		A3: 0.0005 / 0.0005 / 0.0001 / 0.0001 / 0.0001
		A4: 0.005 / 0.0005 / 0.0001 / 0.0005 / 0.001
		A5: 0.0005 / 0.0001 / 0.005 / 0.001 / 0.0001
		A6: 0.0001 / 0.0005 / 0.0005 / 0.0001 / 0.001
		A7: 0.0001 / 0.005 / 0.005 / 0.0001 / 0.005
		A8: 0.0005 / 0.001 / 0.0005 / 0.0001 / 0.0001
RF	The number of trees to be grown in the forest ( $ntree$ )	A1: 100 / 500 / 500 / 100 / 100
		A2: 500 / 100 / 1000 / 500 / 100
		A3: 100 / 100 / 500 / 1000 / 100
		A4: 1000 / 100 / 500 / 100 / 100
		A5: 500 / 100 / 500 / 100 / 100
		A6: 500 / 1000 / 500 / 100 / 100
		A7: 500 / 100 / 100 / 100 / 100
		A8: 100 / 100 / 500 / 100 / 100
	The number of variables for node partitioning ( $mtry$ )	All cases (A1 to A8): $p/2$
CNN-RF	$ntree$	A1: 500 / 500 / 100 / 1000 / 100
		A2: 100 / 500 / 1000 / 1000 / 100
		A3: 100 / 100 / 500 / 500 / 100
		A4: 100 / 500 / 500 / 1000 / 100
		A5: 100 / 100 / 500 / 500 / 1000
		A6: 100 / 500 / 100 / 1000 / 100
		A7: 100 / 100 / 500 / 100 / 1000
		A8: 100 / 100 / 500 / 100 / 100
	$mtry$	All cases (A1 to A8): $\sqrt{p}$

**Table S2.** Optimal hyper-parameter values determined for combination cases of different training data sizes and the lengths of time-series in Hapcheon ( $p$  is the number of input variables).

Model	Hyper-parameter (layer description)	Optimal hyper-parameters (T1/T2/T3/T4/T5)
CNN and CNN-RF	Image patch size	5 × 5
	Convolution layer 1	H1: 256 / 256 / 256 / 256 / 256
	Convolution layer 2	H2: 256 / 256 / 256 / 256 / 256
	Convolution layer 3	H3: 256 / 128 / 256 / 256 / 64
	Dropout	H1: 0.7 / 0.7 / 0.3 / 0.5 / 0.5
		H2: 0.3 / 0.7 / 0.7 / 0.7 / 0.7
		H3: 0.3 / 0.3 / 0.3 / 0.3 / 0.7
	Learning rate	H1: 0.001 / 0.0001 / 0.005 / 0.0005 / 0.001
		H2: 0.0001 / 0.001 / 0.001 / 0.005 / 0.0001
		H3: 0.001 / 0.001 / 0.0001 / 0.001 / 0.001
RF	The number of trees to be grown in the forest ( <i>ntree</i> )	H1: 500 / 500 / 500 / 500 / 500
		H2: 100 / 100 / 1000 / 1000 / 500
		H3: 1000 / 100 / 100 / 500 / 100
CNN-RF	The number of variables for node partitioning ( <i>mtry</i> )	All cases (H1 to H3): $\sqrt{p}$
	<i>ntree</i>	H1: 1000 / 500 / 1000 / 500 / 500
		H2: 100 / 100 / 500 / 100 / 1000
		H3: 100 / 100 / 100 / 500 / 500
	<i>mtry</i>	All cases (H1 to H3): $\sqrt{p}$

**Table S3.** Average overall accuracy with standard deviation of five classification results with respect to combination cases of different training data sizes and the lengths of time-series in Anbandegi (the best case is shown in bold).

Classifier	Date	Training data size				
		T1	T2	T3	T4	T5
RF	A1	54.11 ± 1.22	57.49 ± 1.21	65.35 ± 1.21	69.14 ± 0.69	73.49 ± 0.27
	A2	51.54 ± 2.85	53.75 ± 2.14	63.31 ± 0.44	66.72 ± 0.72	70.53 ± 0.38
	A3	71.92 ± 1.61	72.79 ± 1.61	80.15 ± 0.58	81.57 ± 0.65	85.13 ± 0.35
	A4	69.80 ± 2.53	72.51 ± 1.98	79.79 ± 0.57	81.81 ± 0.55	85.10 ± 0.46
	A5	75.18 ± 1.53	78.79 ± 1.20	82.45 ± 0.79	85.55 ± 0.46	87.62 ± 0.22
	A6	67.28 ± 2.10	74.61 ± 1.20	79.91 ± 0.51	82.88 ± 0.43	85.89 ± 0.32
	A7	80.07 ± 0.54	82.35 ± 0.84	84.85 ± 0.80	88.32 ± 0.51	90.07 ± 0.18
	A8	82.62 ± 1.00	84.93 ± 0.38	86.73 ± 1.12	90.67 ± 0.16	92.23 ± 0.19
CNN	A1	61.70 ± 5.55	69.77 ± 4.05	74.63 ± 3.35	82.64 ± 0.94	83.82 ± 1.21
	A2	69.02 ± 4.15	70.65 ± 5.11	79.57 ± 2.53	83.80 ± 1.24	<b>86.48 ± 0.65</b>
	A3	80.65 ± 2.59	85.06 ± 2.68	90.64 ± 1.19	<b>92.75 ± 0.75</b>	<b>94.35 ± 0.51</b>
	A4	77.94 ± 3.87	82.81 ± 2.55	90.35 ± 0.80	92.64 ± 1.14	<b>94.36 ± 0.25</b>
	A5	83.05 ± 4.81	85.42 ± 3.79	<b>93.05 ± 0.57</b>	94.39 ± 0.70	<b>96.03 ± 0.61</b>
	A6	83.72 ± 5.74	84.53 ± 4.03	91.50 ± 0.93	93.34 ± 0.83	<b>95.57 ± 0.16</b>
	A7	<b>88.68 ± 1.56</b>	91.40 ± 1.92	<b>94.42 ± 0.14</b>	95.61 ± 0.64	97.08 ± 0.16
	A8	<b>92.32 ± 2.13</b>	93.19 ± 0.89	<b>94.86 ± 0.74</b>	96.35 ± 0.58	<b>97.57 ± 0.33</b>
CNN-RF	A1	<b>67.09 ± 4.64</b>	<b>76.47 ± 1.96</b>	<b>79.90 ± 1.25</b>	<b>83.04 ± 0.41</b>	<b>84.94 ± 0.36</b>
	A2	<b>72.31 ± 1.76</b>	<b>75.06 ± 1.91</b>	<b>80.26 ± 1.69</b>	<b>84.02 ± 0.76</b>	86.32 ± 0.63
	A3	<b>82.62 ± 5.12</b>	<b>87.15 ± 2.83</b>	<b>90.96 ± 0.91</b>	92.56 ± 0.77	94.21 ± 0.24
	A4	<b>81.07 ± 3.72</b>	<b>85.88 ± 2.47</b>	<b>90.64 ± 0.48</b>	<b>92.90 ± 0.80</b>	94.34 ± 0.10
	A5	<b>83.58 ± 3.22</b>	<b>86.59 ± 4.64</b>	92.90 ± 0.32	<b>95.07 ± 0.54</b>	95.99 ± 0.26
	A6	<b>85.42 ± 2.00</b>	<b>86.81 ± 3.36</b>	<b>91.70 ± 0.54</b>	<b>94.20 ± 0.70</b>	95.33 ± 0.08
	A7	88.65 ± 1.63	<b>92.13 ± 0.70</b>	94.01 ± 0.17	<b>96.19 ± 0.22</b>	<b>97.16 ± 0.20</b>
	A8	92.24 ± 1.75	<b>93.25 ± 0.71</b>	94.70 ± 0.38	<b>96.38 ± 0.30</b>	97.56 ± 0.23

**Table S4.** Average overall accuracy with standard deviation of five classification results with respect to combination cases of different training data sizes and the lengths of time-series in Hapcheon (the best case is shown in bold).

Classifier	Date	Training data size				
		T1	T2	T3	T4	T5
RF	H1	62.04 ± 2.20	68.33 ± 0.94	73.28 ± 0.78	76.53 ± 0.82	78.99 ± 0.57
	H2	62.16 ± 2.77	71.59 ± 0.76	73.23 ± 0.43	77.58 ± 0.32	80.68 ± 0.40
	H3	63.97 ± 3.11	71.09 ± 1.84	74.11 ± 0.75	79.65 ± 0.53	82.64 ± 0.52
CNN	H1	75.32 ± 3.66	81.26 ± 0.48	82.08 ± 0.96	84.75 ± 0.47	86.53 ± 0.79
	H2	75.18 ± 3.76	79.81 ± 2.19	84.02 ± 1.66	86.60 ± 1.30	87.99 ± 2.23
	H3	74.77 ± 5.19	80.75 ± 1.28	87.82 ± 0.80	90.62 ± 1.08	91.74 ± 0.81
CNN-RF	H1	<b>78.97 ± 2.78</b>	<b>82.61 ± 0.59</b>	<b>85.03 ± 0.52</b>	<b>86.11 ± 0.38</b>	<b>87.16 ± 0.24</b>
	H2	<b>79.79 ± 1.84</b>	<b>83.42 ± 2.01</b>	<b>86.61 ± 0.49</b>	<b>87.59 ± 0.68</b>	<b>88.74 ± 0.30</b>
	H3	<b>78.96 ± 3.99</b>	<b>85.36 ± 0.94</b>	<b>88.43 ± 1.02</b>	<b>90.96 ± 0.75</b>	<b>92.09 ± 0.37</b>